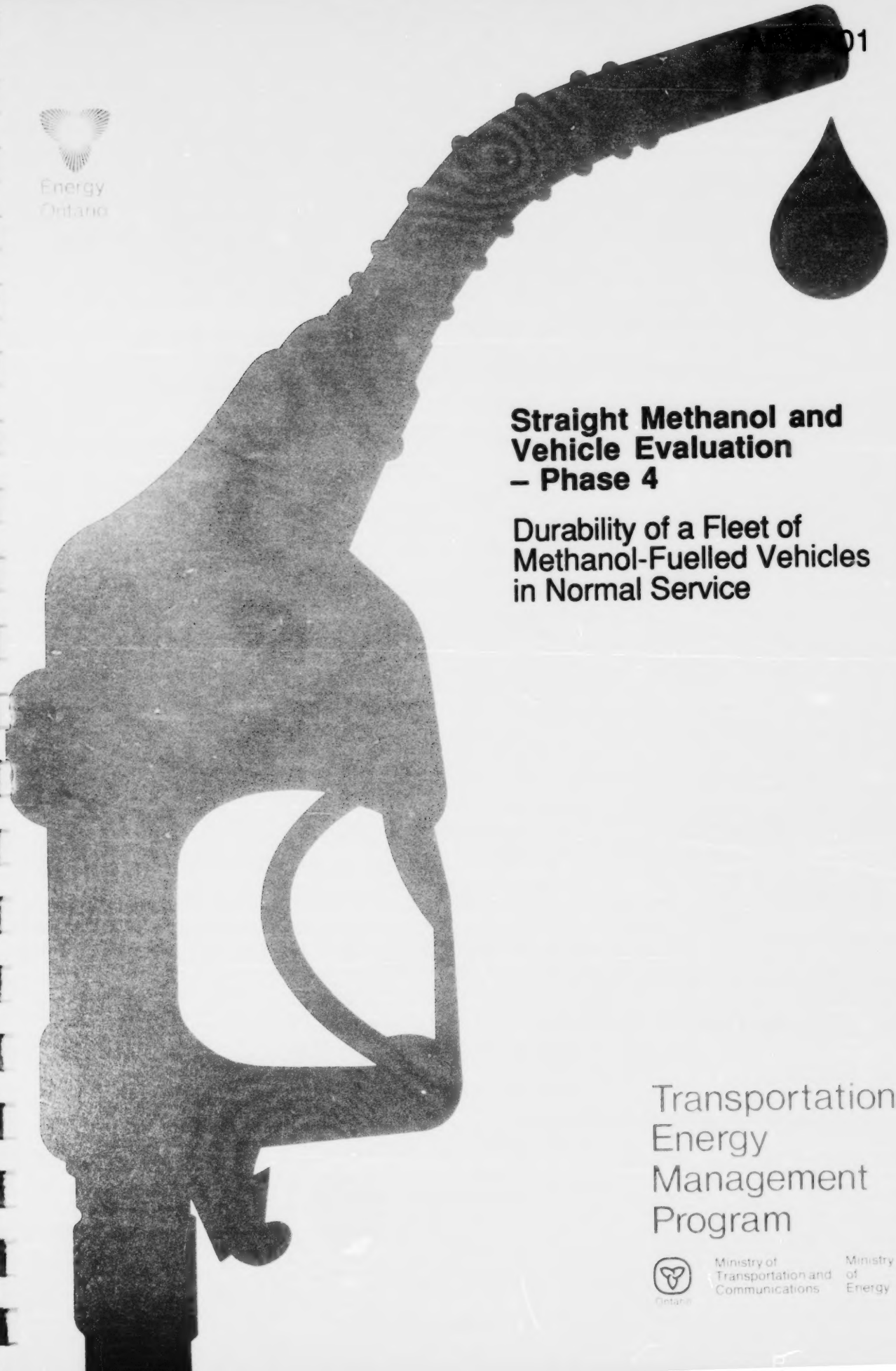
01

Energy
Ontario



Straight Methanol and Vehicle Evaluation – Phase 4

Durability of a Fleet of Methanol-Fuelled Vehicles in Normal Service

Transportation
Energy
Management
Program

Ontario
Ministry of Transportation and Communications
Ministry of Energy

AF-87-01

Straight Methanol and Vehicle Evaluation – Phase 4

Durability of a Fleet of Methanol-Fuelled Vehicles in Normal Service

Prepared for:
D. Elliott
Project Manager
Automotive Technology and Systems Office

Prepared by:
D.K. Mitchell
Research Engineer
Oakville Research Centre
Shell Canada Limited

Participating Agencies
Shell Canada Limited
Ford of Canada Limited
Ontario Ministry of Energy
Ontario Ministry of Transportation and Communications

Published by:
The Transportation Energy Management Program (TEMP)

The Transportation Technology and Energy Branch
Ontario Ministry of Transportation and Communications
Hon. Ed Fulton, Minister
D.G. Hobbs, Deputy Minister

Ontario Ministry of Energy
Hon. Vincent G. Kerrio, Minister
D.M. Allan, Deputy Minister

Published without prejudice
as to the application of the findings.
Crown copyright reserved; however, this
document may be reproduced for non-commercial
purposes with attribution to the Ministry.

For additional copies, write:
The Editor, Technical Publications
Ministry of Transportation and Communications
Room 321, Central Building
1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8
(416) 235-3466

February 1987

Technical Report Documentation Page

MTC Report Number AF-87-01	ISBN Number:	Other Document Number:	Date: Feb. 1987
Title: Straight Methanol and Vehicle Evaluation -- Phase 4 -- Durability of a Fleet of Methanol Fuelled Vehicles			
Authors (name, title and/or organization): D.K. Mitchell, Research Engineer, Oakville Research Centre, Shell Canada Limited			
Published by: The Transportation Energy Management Program Transportation, Technology and Energy Branch, MTC.		**Client Group:**	
Participating Agencies: Shell Canada Limited Ford of Canada Limited Ontario Ministry of Energy Ontario Ministry of Transportation and Communications			

Abstract:
A group of six methanol Ford Escorts has been operated for a year in a mainly highway mode, using specially formulated oils. The oils had been designed from earlier results in previous phases of the program to resist the more aggressive effects of methanol fuel on engine components. Wear effects have been monitored by regular checks on used oil quality and by comparison of the stripped down engine at the beginning and end of the test period.

Key Words: methanol, engine wear, component, durability

Comments:

Distribution: by request

Copyright Status: Crown copyright

DISCLAIMER

The project described in this report was administered by the Ontario Ministry of Transportation and Communications and funded by the Ontario Ministry of Energy. The report is published as a public service. The parties do not, however, warrant the accuracy of its contents and cannot guarantee or assume any liability for the effectiveness of economic benefits of the devices and processes described in the report or that their use does not infringe on privately owned rights.

No company of the Royal Dutch/Shell Group will accept liability for loss or damage originating from the use of the information contained herein.

TABLE OF CONTENTS

	PAGE
DISCLAIMER	ii
EXECUTIVE SUMMARY	v
NOMENCLATURE	vi
1/ INTRODUCTION	1
2/ TEST METHODS	2
2.1/ Test Cars	2
2.2/ Test Fuel	2
2.3/ Test Oils	2
2.4/ Test Parameters	8
2.5/ Test Configuration.	8
3/ RESULTS AND DISCUSSION	10
3.1/ Over-the-Road Fuel Consumption.	10
3.2/ Operational and Maintenance Problems.	10
3.3/ Oil Consumption	12
3.4/ Used-Oil Analysis	12
3.5/ Engine Ratings.	27
3.6/ Engine Wear Results	30
3.7/ Engine Durability	32
3.8/ Comparison with Prior Results	35
4/ CONCLUSIONS	36
5/ RECOMMENDATIONS	37
6/ REFERENCES	38
APPENDICES	
A/ Test Car Identification	40
B/ Used-Oil Analysis Result Interpretation	42
C/ New Oil Infrared Scans.	44
D/ Selected Used-Oil Infrared Scan	51
E/ A Survey of Gasoline Engine Field Tests	59
F/ Car 306 Test Data	72

LIST OF TABLES

PAGE

1/ Test Vehicle Specifications 3
2/ Test Fuel Blend Inspection Properties 4
3/ Base Component Inspection Properties. 5
4/ Test Oil Inspection Properties. 6
5/ Over-The-Road Fuel Consumption. 11
6/ Oil Test Matrix 13
7/ Used-Oil Analysis, Car 333, Oil A 14
8/ Used-Oil Analysis, Car 334, Oil B 15
9/ Used-Oil Analysis, Car 335, Oil C 16
10/ Used-Oil Analysis, Car 342, Oil B 17
11/ Used-Oil Analysis, Car 343, Oil C 18
12/ Used-Oil Analysis, Car 344, Oil A 19
13/ Engine Valves Ratings 28
14/ Engine Ratings. 29
15/ Engine Wear Results -- Dimensional. 31
16/ Sequence III-D and V-D Test Results for Oil C 33
17/ Engine Wear Results -- Weight 34

LIST OF FIGURES

1/ Used-Oil Analysis -- Car 333, Oil A. 20
2/ Used-Oil Analysis -- Car 334, Oil B. 21
3/ Used-Oil Analysis -- Car 335, Oil C. 22
4/ Used-Oil Analysis -- Car 342, Oil B. 23
5/ Used-Oil Analysis -- Car 343, Oil C. 24
6/ Used-Oil Analysis -- Car 344, Oil A. 25

EXECUTIVE SUMMARY

The work described in this report is part of a long-term program to evaluate the performance of methanol-fuelled vehicles. It has been directed by the Ontario Ministry of Transportation and Communications and jointly funded by the Ontario Ministry of Energy, Ford Canada, and Shell Canada.

Six Ford Escorts which have been modified by the manufacturer to run on fuel-methanol have now been operated for one year in normal long-distance service using three different test oils. The oils were formulated with proprietary additive packages, one supplied by Shell itself and two others from outside companies. The formulations had been identified from earlier phases of the study as promising a level of protection for the special needs of methanol engines.

The results indicate that the three test oils are equivalent in performance over the duration of the study in their effect on wear, engine durability, and cleanliness in a mainly highway-style, long-trip distance accumulation mode. In contrast to the more severe short-trip distance accumulation test performed in Phase 3, the results for the present test were not significantly worse than expected for an equivalent gasoline engine, but with an oil drain period reduced by approximately 58%.

Generally, as ambient temperature decreases, wear increases with methanol-fuelled engines. To address the concern that engine life with fuel-methanol is reduced over that with gasoline, a much longer term test with gasoline control vehicles would be desirable.

NOMENCLATURE

C	- carbon
CO	- carbon monoxide
cSt	- centistokes
CRC	- Co-ordinating Research Council
Δkm	- difference in kilometres
DME	- dimethyl ether
EP	- end point
EPA	- Environmental Protection Agency
E	- exhaust
g	- grams
hr	- hour
HC	- hydrocarbon
H	- hydrogen
IBP	- initial boiling point
I	- intake
kg	- kilogram
km	- kilometre
KOH	- potassium hydroxide
L	- litre
MJ	- megajoules
MeOH	- methanol
mi	- mile
mm	- millimetre
OHC	- overhead cam
NO_x	- oxides of nitrogen
O	- oxygen
ppm	- parts per million
% evap.	- % evaporated in the ASTM-D-86 distillation test
RVP	- Reid vapour pressure by ASTM D-323
SAE	- Society of Automotive Engineers
SNL-W	- super non-leaded - winter grade
TAN	- total acid number by ASTM D-664
TBN	- total base number by ASTM D-664 or D-2896
TC	- Transport Canada
VII	- viscosity index improver

1/ INTRODUCTION

"Fuel-methanol", or near-neat methanol fuel, is considered to be a possible future alternative to conventional hydrocarbon fuels. Shell Canada, in association with Ford of Canada, has operated a small fleet of 1983 Ford Escorts, built to operate on fuel-methanol, for approximately two years.

This program, now in its fourth phase, was jointly funded by Ford and Shell and the provincial government under the Transportation Energy Management Program (TEMP), administered by the Ontario Ministry of Transportation and Communications and the Ministry of Energy.

Phase 1 of this program addressed problems with cold weather operation of these methanol-fuelled Ford Escorts. Phase 2 concerned the durability of these vehicles via a long-term fleet test under Canadian climatic conditions. Phase 3 concerned a test of six of these cars under short-trip driving conditions. Phase 4, as detailed in this report, concerns a test of six of these cars under normal-service (approximately 30% urban/70% highway) driving conditions.

2/ TEST METHODS

2.1/ Test Cars

The vehicles in the test fleet were 1983 Ford Escorts developed by the manufacturer to operate on fuel-methanol. The cars were built primarily for use in California and, as such, were developed for its mild climate. Originally, this fuel was specified as a blend of 90% by volume methanol and 10% by volume winter-grade non-leaded gasoline. Then the manufacturer, the Ford Motor Company, changed the specification to 85% by volume methanol and 15% by volume high aromatic (greater than 40% by volume) winter grade non-leaded gasoline, prior to this phase. The fuel specification was changed to help ensure flame visibility under worst case conditions.

Test car specifications are given in Table 1 and the cars are identified in Appendix A. Three vehicles were operated at Shell Canada, and three at Ford of Canada. All six cars were used in Phase 2 of this program.

The cars were calibrated to meet the 1983 California emission standards. The maximum emission levels under this standard are 0.39 g hydrocarbon (HC)/mi (0.24 g HC/km) (non-methane standard), 7 g/carbon monoxide (CO)/mi (4.3 g CO/km), and 0.7 g nitrogen oxides(NO_x)/mi (0.43 g NO_x/km).

2.2/ Test Fuel

The test fuel used, fuel-methanol, or near-neat methanol, varied during the test period. Table 2 lists the inspection properties of the five fuel blends used, from January 1985 until December 1985, and the inspection properties of the blends. Table 3 details the properties of the fuel blend components. The fuel blends varied mainly in energy content and volatility. The test fuel was stored and dispensed from two 4546 L (1000 imp. gal) stainless steel, above-ground, storage tanks at both the Ford and Shell locations.

2.3/ Test Oils

The major concern in Phase 4 was to evaluate engine durability under normal driving conditions. Three different oils were blended for use in the six-car test fleet. Table 4 details the inspection properties of the three oils, which were blended using Shell Canada and synthetic base stocks and three different additive packages:

Table 1/ Test Vehicle Specifications

Model	1983 Ford Escort
Body Styles	4-door hatchback -- station wagon
Engine Type	OHC, in-line 4 cylinder
Bore x Stroke	80 x 79 mm
Capacity	1.6 L
Compression Ratio	11.8:1
Power Output	85 hp @ 5200 rpm
Top Ring Type	barrel-faced, chrome-plated
Head Gasket	1984 type -- stainless steel fire rings
Camshaft Type	base
Distributor	modified spark curve (vs gasoline version)
Spark Plug Type	AGSF12C
Fuel System Specifications	- stainless steel fuel tank - stainless steel fuel lines - nickel-plated in-tank sending unit - nylon-coated fuel tank straps - nickel-plated fuel pump - nickel-plated, recalibrated carburetor - new carburetor spacer with electrical heating unit

Table 2/ Test Fuel Blend Inspection Properties

	Blend 9		Blend 10		Blend 11		Blend 12		Blend 13	
	by vol %	by mass %	by vol %	by mass %	by vol %	by mass %	by vol %	by mass %	by vol %	by mass %
Component										
Methanol (MeOH)	77.7	79.4	84.4	85.4	85.0	85.9	85.0	85.9	85.0	85.8
Super Non-Leaded Gasoline (SNL)	14.7	14.2	15.0	14.1	15.0	14.1	15.0	14.1	15.0	14.2
Dimethyl Ether (DME)	7.6	6.4	0.6	0.5	-	-	-	-	-	-
Time Period	Jan. 10/85 to Feb. 20/85		Feb. 21/85 to May 15/85		May 16/85 to July 26/85		July 27/85 to Oct. 22/85		Oct. 23/85 to Dec. 31/85	
Inspection Properties										
Density, kg/L	0.780		0.786		0.789		0.789		0.789	
ASTM D-86 Distillation:										
IBP, °C	31		59		49		59		49	
10%, °C	45		61		62		61		63	
50%, °C	64		64		64		64		65	
90%, °C	65		64		65		64		66	
EP, °C	169		66		65		66		163	
% recovery	94.1		98.0		98.8		98.1		98.4	
C	45.4		44.5		44.4		44.4		44.4	
H	12.7		12.6		12.6		12.6		12.6	
O	41.9		42.9		43.0		43.0		43.0	
RVP (dry), kPa (psi)	122(17.7)		65.2(9.5)		56(8.1)		53.1(7.7)		53.7(7.8)	
Water Content, mg/kg	332		132		273		549		313	
Chloride Content, mg/kg	2.5		1.8		<1.0		<1.0		<1.0	
Calculated Energy Content MJ/kg	23.8		23.3		23.2		23.2		23.2	
(net or LH value) MJ/L	18.5		18.4		18.3		18.3		18.3	
Ratio of Energy Contents, Blend 9/Blend N	1.000		1.005		1.011		1.011		1.011	

Table 3/ Base Component Inspection Properties

Component	SNL (Blends 9,10)	SNL (Blends 11,12,13)	DME	MeOH (Typ.)
Inspection Properties				
Density, kg/L	0.742	0.748	0.661	0.797
ASTM D-86 Distillation:				
IBP, °C	27	32	-25	64
10%, °C	40	52	-	64
50%, °C	106	109	-	64
90%, °C	155	153	-	64
EP, °C	195	204	-25	67
% recovery	93.2	96.8	-	99.8
C, % by mass	86.6	86.6	52.1	37.5
H, % by mass	13.4	13.4	13.0	12.5
O, % by mass	-	-	34.9	50.0
RVP (dry), kPa (psi)	94.2(13.7)	69.0(10.0)	850(123)	30.2(4.4)
Water Content, mg/kg	125	-	-	425
Cl, mg/kg	<1.0	-	-	<1.0
Energy Content MJ/kg (book value)	43.5	43.5	28.9	19.9
(net or LH value) MJ/L	32.2	32.2	19.1	15.9

Table 4/ Test Oil Inspection Properties

	Oil Type					Original Oils	
	Oil A		Oil B	Oil C			
SAE Viscosity Grade	10W20	15W30	10W30	10W20	15W30	10W20	10W30
Components							
Base Oil	✓	✓	✓	✓	✓	✓	✓
Synthetic Oil	✓	✓		✓	✓	✓	✓
Additive Package	✓	✓	✓	✓	✓	✓	✓
Inspection Properties							
Viscosity @ 40°C, cSt	56.3	77.9	68.1	51.4	74.5	52.4	77.6
Viscosity @ 100°C, cSt	8.7	10.5	10.7	7.8	10.2	8.3	10.8
CCS Viscosity @ -15°C, cP		3250			3280		3325
CCS Viscosity @ -20°C, cP	3100	-	2850	3400	-	2750	-
Pour Pt., °C	-48	-36	-45	-18	-21	-42	-42
Density, kg/L	0.888	0.888	0.883	0.885	0.887	0.890	0.893
Sulphated Ash, % by mass	1.59	1.53	1.51	1.56	1.57	2.88	2.89
Mg, mg/kg	<1.0	<1.0	7.1	2378	2240	24	24
Zn, % by mass	0.18	0.17	0.15	0.16	0.16	0.19	0.19
Ca, % by mass	0.35	0.36	0.34	0.10	0.09	0.77	0.76
P, % by mass	0.16	0.16	0.10	0.13	0.13	0.16	0.16
TAN, D-664, mg KOH/g	2.0	1.9	2.7	2.5	2.9	2.4	2.3
TBN, D-664, mg KOH/g	14.0	13.8	6.2	12.9	12.8	12.4	12.8
TBN, D-2896, mg KOH/g	14.8	16.6	10.3	14.2	13.0	16.6	16.8

1/ one developed by Shell Canada at the Oakville Research Centre;
2/ one developed by Paramins, a division of Exxon, as a replacement for its original package as used by the Ford Motor Company in their methanol factory-fill oil;
3/ one developed by the Lubrizol Corporation for use in light-duty methanol-fuelled engines.

Two of the oils were blended in two viscosity grades: a 10W20 grade for winter and a 15W30 grade for summer. The other oil was blended in a 10W30 grade.

These additive packages were developed specifically for fuel-methanol engines because results from earlier testing by various researchers indicated that normal gasoline engine lubricants would not give acceptable engine durability [1-6]. Engine wear with methanol fuel, instead of gasoline, increased at lower oil temperatures (i.e., less than 70°C) and was principally in the upper cylinder bores and piston rings, with some wear of the cam lobes, followers, and bearings. Rusting of the cylinder bores and crankshaft journals also occurred. In some studies [7], increased intake system deposits occurred, because the viscosity index improver (VII) in the oil degraded upon contact with the methanol.

The wear associated with the use of fuel-methanol appears to have the following mechanism: incompletely vaporized methanol condenses on the cylinder walls and, because of its polar nature, penetrates or removes the oil film. During combustion, various intermediate compounds, including gaseous formaldehyde, peroxides, and water, are formed. These compounds diffuse to the methanol film now on the cylinder wall and are dissolved in it. Formic acid is formed and reacts with the iron to form iron formate, which then decomposes to iron oxide and is removed by the passage of the piston rings up and down the cylinder bore. These abrasive particles can then find their way to other areas of the engine and cause increased wear.

The rusting of engine components is most likely due to emulsions of fuel-methanol, water, and engine oil, which occur during cold operation, sitting on metal surfaces and causing corrosion. This is due to the chemically reactive, polar, and hygroscopic natures of methanol.

To combat these problems, the three additive packages were developed. Because all three are proprietary to the suppliers involved, only a few generalities can be made:

1/ No or very little viscosity index improver was used in the oils as this has been shown to cause intake system deposits.
2/ As more wear occurs at a lower temperature regime than with gasoline, more and different anti-wear additives have been used.
3/ To combat the formation of formic acid, more detergent has been added to the oil. This is indicated by the total base number (TBN), either by ASTM D-664 or D-2896.
4/ An anti-corrosion additive could be used to help alleviate the rusting of engine components.

2.4/ Test Parameters

Phase 4 was intended to complement the work already undertaken in Phase 3.

Evaluations of the test fleet included the following:
1/ operations and maintenance over the one-year test period;
2/ engine durability via pre- and post-test engine component measurements, used-oil analysis, and engine cleanliness, on the three Shell cars, and via used-oil analysis on the three Ford Cars.

2.5/ Test Configuration

The six cars were operated under normal conditions. The kilometre accumulation at Shell was via employee use of the test cars both during and outside working hours. The kilometre accumulation at Ford was via assigned employee use of the test car.

Components of the three cars were pre-measured:
- cylinder bore diameter, both longitudinal and transverse, at three locations: the top, middle, and bottom of the ring travel region (four sets);
- piston skirt diameter (four);
- ring gap, top and middle rings (four sets);
- ring weight, top and middle rings (four sets);
- ring side clearances, top and middle rings (four sets);
- rod bearing weights (four sets);
- main bearing weights (five sets);
- valve stem diameter, intake and exhaust (four sets);
- valve guide internal diameter, intake and exhaust (four sets);
- valve tip height, intake and exhaust (four sets);
- camshaft lobe heights, intake and exhaust (four sets);
- rocker arm weights (four sets);
- rocker arm pivot weights (four sets);
- valve weights (four sets);

- main bearing journal diameters, horizontal and vertical (five sets);
- connecting rod journal diameters, horizontal and vertical (four sets).

All three Shell cars were rated at the end of test for the following:

- sludge deposits - rocker arm cover
  - front seal housing
  - oil pan
  - valve deck area
  - block underside
- varnish deposits - piston skirts
  - rocker arm cover
  - cylinder wall (below ring travel)
  - oil pan
- stuck components - rings, lash adjusters
- clogging - oil rings, oil screens
- valve deposits

All these were rated by Co-ordinating Research Council (CRC) methods.

Used-oil analysis was also used to monitor engine durability. Appendix B lists some data which give warning levels for used engine oils, and Appendices C and D give infrared scans for the new and selected used oils, respectively. The Shell cars had their oils sampled and tested after nominally 1000, 2000, 3000, and 5000 km of operation on the test oil. After this initial drain, the oils were sampled at the next three 5000 km drains.

The Ford cars had their oils sampled at three consecutive 5000 km drains. In Phase 2 of this program, a similar evaluation of one oil was undertaken, with an identical drain period of 5000 km but an average accumulation of 24 000 km.

3/ RESULTS AND DISCUSSION

3.1/ Over-the-Road Fuel Consumption

The fuel consumption results have been grouped by fuel blend. As previously described, the fuel blend changed over the test period each time the 4546 L (1000 imp. gal) storage tanks were refilled.

Table 5 shows the fuel consumption results for the six individual cars. Some effect of the variation in fuel properties, as given in Table 2, would be expected.

The fuel consumption was lowest in the May to October 1985 (Blends 11 and 12) period and highest in the months of January and February 1985 (Blend 9). The fuel consumption in the latter period was 25 to 30% higher than in the former period. This compares to values of 30 and 25% from Phases 2 and 3 [8,9].

The energy content of the five fuel blends varied between 18.5 and 18.3 MJ/L. Combining these values (given in Table 2) and the overall average fuel consumptions of 18.8 L/100 km with Blend 9 (winter) and 14.7 L/100 km with Blends 11 and 12 (summer) gives energy consumption values ranging from 350 to 270 MJ/100 km. A gasoline Ford Escort, tested by Transport Canada, gave an urban rating of 9.4 L/100 km and a combined rating of 7.5 L/100 km, which equates to 303 and 242 MJ/100 km, respectively [10]. These values compare quite favourably with the result of Blends 11 and 12 (namely, 270 MJ/100 km).

The fuel consumption records from the three Ford of Canada cars were not as complete, so smaller periods were used to typify each blend's fuel consumption. Typically, no more than 46 L of fuel were installed in any of the cars at one time, notwithstanding the tank capacity of 49.2 L. Using the former value, the average vehicle range in winter would be 250 km, and in summer, 320 km.

3.2/ Operational and Maintenance Problems

The operational problems encountered were the same as in the previous phases of this program [1,8,9]. The comments, by the drivers, concerned poor cold startability, stalling during warm-up, rough idle quality, and stumble on shift changes.

Block heat was used 10 times by the three Shell cars. None of the six cars even failed to start during the one-year test period. All six cars were recalibrated in January 1985, as reported in Phase 3 [9]. This

Table 5/ Over-the-Road Fuel Consumption

Blend No.	Time Period	Units	333	334	335	Average	342	343	344	Average
9	Jan.10/85 to	L/100 km	17.76	19.05	-[1]	18.4	21.07	-[1]	17.36	19.2
	Feb. 20/85	MPIG	15.91	14.83	-	15.4	13.41	-	16.27	14.7
		L	502	665	-		71	-	234	
		km	2826	3491	-		337	-	1348	
10	Feb. 21/85 to	L/100 km	16.62	16.31	16.23	16.4	16.83	17.18	15.09	16.4
	May 15/85	MPIG	17.00	17.32	17.40	17.2	16.78	16.44	18.72	17.3
		L	748	591	734		406	252	459	
		km	4499	3624	4523		2412	1467	3041	
11	May 16/85 to	L/100 km	14.25	14.83	14.01	14.4	16.48	14.49	13.28	14.8
	July 26/85	MPIG	19.82	19.05	20.16	19.7	17.14	19.49	21.27	19.2
		L	585	629	634		635	664	532	
		km	4106	4242	4524		3852	4581	4007	
12	July 27/85 to	L/100 km	15.34	15.04	14.21	14.9	17.17	14.31	12.50	14.7
	Oct. 21/85	MPIG	18.41	18.78	19.88	19.0	16.45	19.74	22.60	19.3
		L	853	681	751		746	476	719	
		km	5559	4524	5286		4345	3326	5751	
13	Oct. 22/85 to	L/100 km	15.60	16.10	16.03	15.9	17.05	19.30	17.26	17.9
	Dec. 31/85	MPIG	18.11	17.55	17.62	17.8	16.57	14.64	16.37	15.8
		L	452	523	588		412	261	434	
		km	2897	3248	3668		2416	1352	2515	

MIPG = 282.48/(L/100 km)

MPUSG = 235.22/(L/100 km)

[1]Insufficient data available for meaningful fuel consumption results.

calibration was intended to improve cold weather driveability by enriching the mixture after cold starts, reducing stumble on shift changes, and improving the ignition quality. The recalibration did improve the cold weather driveability of the cars.

Few fuel-related maintenance problems were encountered. The side electrodes of two spark plugs were lost in two cars. This problem occurred in earlier phases of this program. In Phase 1 and the early part of Phase 2, this problem was quite common as the original spark plugs were manufactured with incorrect side electrodes. Subsequently, the plugs were changed (to type AGSF12C), which used the correct side electrodes. In Phase 2, two cars had spark plug damage on the revised plug type. This problem seems isolated in nature.

Car 343 had some excessive cam wear problems. At 50 000 km, the camshaft proved to be excessively worn, particularly the number 4 intake lobe. The cam and lifters were replaced. This failure does not appear to be related to oil quality. At 54 040 km, this car, number 343, was dismantled, as it had a loud engine rattle. No excessively worn parts were found; however, the crankshaft thrust bearing was replaced as a precautionary measure.

Car 335 also exhibited a higher than normal level of cam wear. Again, this did not appear to be related to oil quality. It is possible these cams were manufactured incorrectly. These problems will be discussed further in Section 3.6.

3.3/ Oil Consumption

Table 6 lists the oil test matrix. Cars 333 and 344, on oil A, used an average of 700 mL/5000 km drain; cars 334 and 342, on oil B, used an average of 600 mL/5000 km drain; cars 335 and 343, on oil C, used an average of 100 mL/5000 km drain. Oils A and C were blended in summer (SAE 15W30) and winter (SAE 10W20) grades, while oil B was blended in an SAE 10W30 grade for year-round use.

3.4/ Used-Oil Analysis

Tables 7 through 12 show the used engine oil test results of the six cars. The results are shown graphically in Figures 1 to 6. Table 4 gives the inspection properties of the test oils.

All the pentane insoluble levels were acceptable. Pentane insolubles include oil-insoluble matter caused by contamination and oil insoluble matter caused by oil or additive package degradation. The levels in this Phase 4 are lower than the normal-service cars in Phase 2.

Table 6/ Oil Test Matrix

Car No.	333	334	335	342	343	344
Oil Type	A	B	C	B	C	A
1st Oil Drain						
Oil Grade	10W20	10W30	10W20	10W30	10W20	10W20
Initial km Reading	4 411	4 247	4 865	31 082	37 554	27 291
Final km Reading	9 477	7 242	10 310	37 822	47 039	35 117
Δkm	5 066	2 995	5 445	6 740	9 485	7 826
2nd Oil Drain						
Oil Grade	10W20	10W30	15W30	10W30	10W20	10W20
Initial km Reading	9 477	7 242	10 310	37 822	47 039	35 117
Final km Reading	11 050	12 404	14 868	45 092	50 000	41 571
Δkm	1 573	5 162	4 558	7 270	2 961	6 454
3rd Oil Drain						
Oil Grade	10W20	10W30	15W30	10W30	10W20	15W30
Initial km Reading	11 050	12 404	14 868	45 092	50 000	41 571
Final km Reading	16 122	17 792	19 868	48 669	54 077	46 847
Δkm	5 072	5 388	5 000	3 577	4 077	5 276
4th Oil Drain						
Oil Grade	15W30	10W30	15W30			
Initial km Reading	16 122	17 792	19 868			
Final km Reading	20 983	22 656	23 976			
Δkm	4 861	4 864	4 108			
5th Oil Drain						
Oil Grade	15W30	10W30				
Initial km Reading	20 983	22 656				
Final km Reading	25 981	27 635				
Δkm	4 998	4 979				
Total Δkm	20 770	22 388	19 111	17 587	16 523	19 556

Table 7/ Used-Oil Analysis, Car 333, Oil A

Oil Grade	10W20	15W30	10W20	10W20	10W20	10W20	10W20	10W20	10W20	10W20	15W30	15W30
km	0.0	0.0	5851	6714	7940	8699	9477	10 444	11 050	16 122	20 933	25 981
TAN, D-664	2.0	1.9							5.6	4.0	4.5	3.7
TBN, D-664	14.0	13.8							3.8	4.1	4.9	8.5
TBN, D-2896	14.8	16.6							11.6	12.3	13.1	12.4
Fuel Dilution (FD), D-322	0.0	0.0							0.4	0.1	0.4	0.8
Visc @ 40°C, cSt	56.3	77.9							-	-	69.3	64.3
100°C, cSt	8.7	10.5	7.7	7.7	7.8	FD[1]	7.9	10.2	8.0	8.1	9.8	FD[1]
Pentane Insols., D-893	0.0	0.0	0.03	0.10	0.09	0.13	0.16	0.50	0.10	0.17	0.17	0.40
Al, ppm	0	0	8.8	11.1	13.2	14.4	15.6	15.4	16.3	6.8	5.9	7.9
Cr, ppm	0	0	3.8	4.5	5.7	14.6	19.4	20.0	22.4	4.9	3.2	6.2
Cu, ppm	0	0	12.3	15.1	18.1	24.3	28.2	26.6	29.0	26.7	7.8	6.0
Fe, ppm	0	0	54.9	57.4	60.2	73.1	79.0	69.3	75.1	54.1	46.8	41.4
Pb, ppm	0	0	32.6	34.9	33.7	48.0	52.1	49.1	51.0	24.4	14.3	13.2
Si, ppm	0	0	29.9	37.4	31.4	32.3	33.2	32.1	32.4	9.7	9.5	7.0
km on Oil	0	0	1440	2303	3529	4288	5066 Drain	967	1573 Drain	5 072 Drain	4 861 Drain	4 998 Drain
Total km on Test	0	0	1440	2303	3529	4288	5066	6033	6639	11 711	15 772	20 770

[1]FD = Fuel dilution invalidates test

Table 8/ Used-Oil Analysis, Car 334, Oil B

Oil Grade	10W30	10W30	10W30	10W30	10W30	10W30	10W30	10W30
km	0.0	5247	6246	7242	12 404	17 792	22 656	27 635
TAN, D-664	2.7			4.0	2.6	2.9	2.9	3.1
TBN, D-664	6.2			3.3	3.7	6.3	4.5	6.2
TBN, D-2896	10.3			8.9	8.8	8.8	9.2	6.8
FD, D-322	0.0			0.8	-	0.6	0.2	-
Visc @ 40°C, cSt	68.1				-	-	57.6	53.8
100°C, cSt	10.7	9.3	8.7	FD[1]	FD[1]	9.1	9.3	FD[1]
Pentane Insols., D-893	0.0	0.10	0.22	0.29	0.19	0.14	0.19	0.49
Al, ppm	0	7.5	7.5	8.3	11.4	4.5	5.2	7.1
Cr, ppm	0	1.3	3.5	6.0	2.7	2.2	3.0	7.3
Cu, ppm	0	3.7	6.5	8.5	14.1	4.8	3.9	4.1
Fe, ppm	0	18.7	28.5	36.4	69.8	44.0	37.1	45.0
Pb, ppm	0	14.1	19.2	20.5	38.1	13.9	17.1	16.8
Si, ppm	0	11.2	12.5	11.1	29.5	9.0	7.7	8.3
km on Oil	0	1000	1999	2995 Drain	5162 Drain	5 388 Drain	4 864 Drain	4 979 Drain
Total km on Test	0	1000	1999	2995	8157	13 545	18 409	22 388

[1]FD = Fuel dilution invalidates test

Table 9/ Used-Oil Analysis, Car 335, Oil C

Oil Grade	10W20	15W30	10W20	10W20	10W20	10W20	10W20	15W30	15W30	15W30
km			5902	6909	7848	8818	10 310	14 868	19 868	23 976
TAN, D-664	2.5	2.9					3.0	2.6	4.6	4.9
TBN, D-664	12.9	12.8					10.7	11.4	12.3	12.0
TBN, D-2896	14.2	13.0					13.9	13.1	10.2	13.3
FD, D-322	0.0	0.0					0.4	0.2	0.4	-
Visc @ 40°C, cSt	51.4	74.5					49.2	72.5	72.1	69.6
100°C, cSt	7.8	10.2	7.4	7.4	7.6	7.7	FD[1]	10.0	FD[1]	9.7
Pentane Insols., D-893	0.0	0.0	0.17	0.28	0.50	0.33	0.79	0.15	0.57	0.10
Al, ppm	0.0	0.0	5.1	9.2	11.3	11.2	12.4	7.7	10.1	13.0
Cr, ppm	0.0	0.0	3.3	6.8	7.9	3.0	4.1	2.3	1.5	6.0
Cu, ppm	0.0	0.0	6.6	15.1	19.3	20.0	19.0	8.6	7.7	21.7
Fe, ppm	0.0	0.0	19.1	39.1	45.6	56.4	62.1	35.5	39.3	61.0
Pb, ppm	0.0	0.0	24.7	49.0	61.4	64.4	70.1	26.6	19.0	29.0
Si, ppm	0.0	0.0	21.8	29.6	32.1	20.0	36.3	17.6	13.4	14.4
km on Oil	0.0	0.0	1037	2044	2983	3953	5445 Drain	4 558 Drain	5 000 Drain	4 108 Drain
Total km on Test	0.0	0.0	1037	2044	2983	3953	5445	10 003	15 003	19 111

[1]FD = Fuel dilution invalidates test

Table 10/ Used-Oil Analysis, Car 342, Oil B

Oil Grade	10W30	10W30	10W30	10W30
km	0.0	37 822	45 092	48 669
TAN, D-664	2.7	3.1	2.8	2.3
TBN, D-664	6.2	7.3	6.0	8.3
TBN, D-2896	10.3	9.7	7.6	11.9
FD, D-322	0.0	0.8	0.8	1.0
Visc @ 40°C, cSt	68.1	-	58.7	56.1
100°C, cSt	10.7	9.3	9.3	8.9
Pentane Insols., D-893	0.0	0.29	0.22	0.26
Al, ppm	0.0	14.2	7.9	6.9
Cr, ppm	0.0	7.7	6.0	5.2
Cu, ppm	0.0	34.0	12.7	12.5
Fe, ppm	0.0	81.0	54.0	41.8
Pb, ppm	0.0	49.5	25.3	25.9
Si, ppm	0.0	12.1	10.2	12.6
km on Oil	0.0	6740 Drain	7 270 Drain	3 577 Drain
Total km on Test	0.0	6740	14 010	17 587

Table 11/ Used-Oil Analysis, Car 343, Oil C

Oil Grade	10W20	15W30	10W20	10W20	10W20
km	0.0	0.0	47 039	50 000	54 077
TAN, D-664	2.5	2.9	4.8	4.7	5.2
TBN, D-664	12.9	12.8	7.8	11.5	9.4
TBN, D-2896	14.2	13.0	9.9	13.8	14.5
FD, D-322	0.0	0.0	0.4	0.1	-
Visc @ 40°C, cSt	52.4	77.6	-	70.2	69.9
100°C, cSt	8.3	10.8	7.9	FD[1]	9.8
Pentane Insols., D-893	0.0	0.0	0.43	0.47	0.24
Al ppm	0.0	0.0	12.1	10.8	8.8
Cr ppm	0.0	0.0	14.0	3.0	19.1
Cu ppm	0.0	0.0	33	21.6	8.4
Fe ppm	0.0	0.0	120	58.5	44.4
Pb ppm	0.0	0.0	54.7	51.4	21.3
Si ppm	0.0	0.0	15.6	16.4	27.6
km on Oil	0.0	0.0	9485 Drain	2 961 Drain	4 077 Drain
Total km on Test	0.0	0.0	9485	12 446	16 523

[1]FD = Fuel dilution invalidates test

Table 12/ Used-Oil Analysis, Car 344, Oil A

Oil Grade	10W20	15W30	10W20	10W20	15W30
km	0.0	0.0	35 117	41 571	46 847
TAN, D-664	2.0	1.9	3.6	3.8	3.7
TBN, D-664	14.0	13.2	7.7	6.3	10.2
TBN, D-2896	14.8	16.6	12.6	10.4	13.3
FD, D-322	0.0	0.0	0.8	0.4	
Visc @ 40°C, cSt	56.3	77.9	57.6	53.5	65.7
100°C, cSt	8.7	10.5	8.6	8.3	9.4
Pentane Insols., D-893	0.0	0.0	0.03	0.23	0.37
Al ppm	0.0	0.0	14.4	6.9	7.7
Cr ppm	0.0	0.0	15.8	6.1	7.5
Cu ppm	0.0	0.0	6.8	18.1	18.3
Fe ppm	0.0	0.0	128	90.6	65.3
Pb ppm	0.0	0.0	68.3	28.3	42.9
Si ppm	0.0	0.0	18.1	5.8	14.6
km on Oil	0.0	0.0	7826 Drain	6 454 Drain	5 276 Drain
Total km on Test	0.0	0.0	7826	14 280	19 556

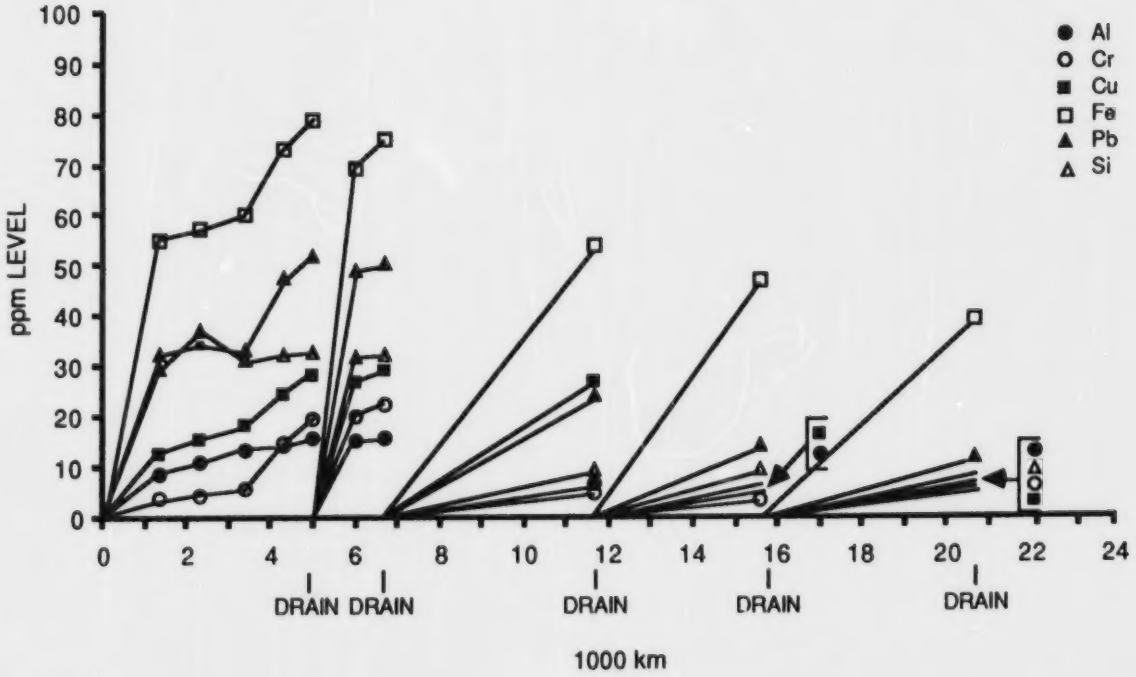


Figure 1/ Used-Oil Analysis – Car 333, Oil A

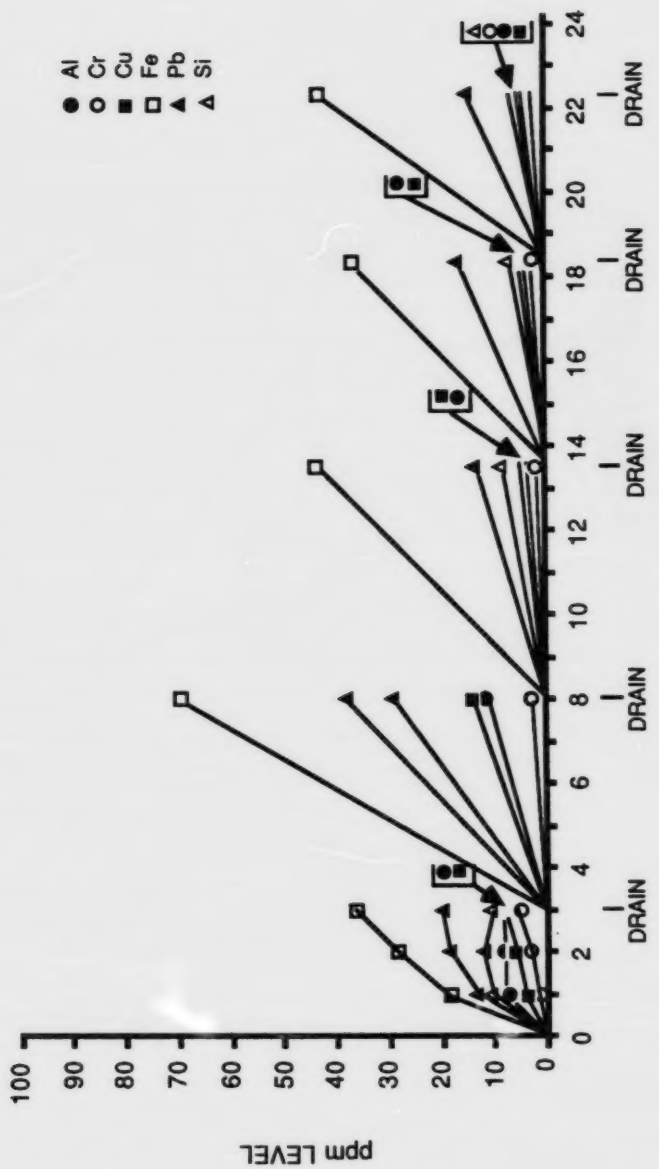


Figure 2/ Used-Oil Analysis – Car 334, Oil B

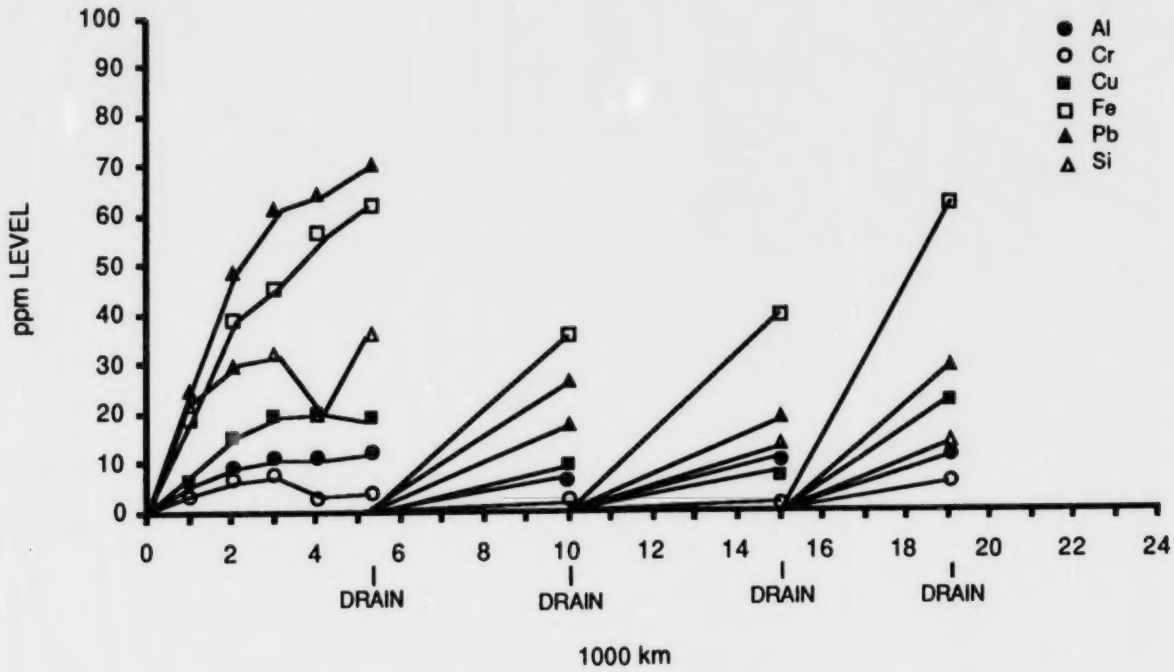


Figure 3/ Used-Oil Analysis – Car 335, Oil C

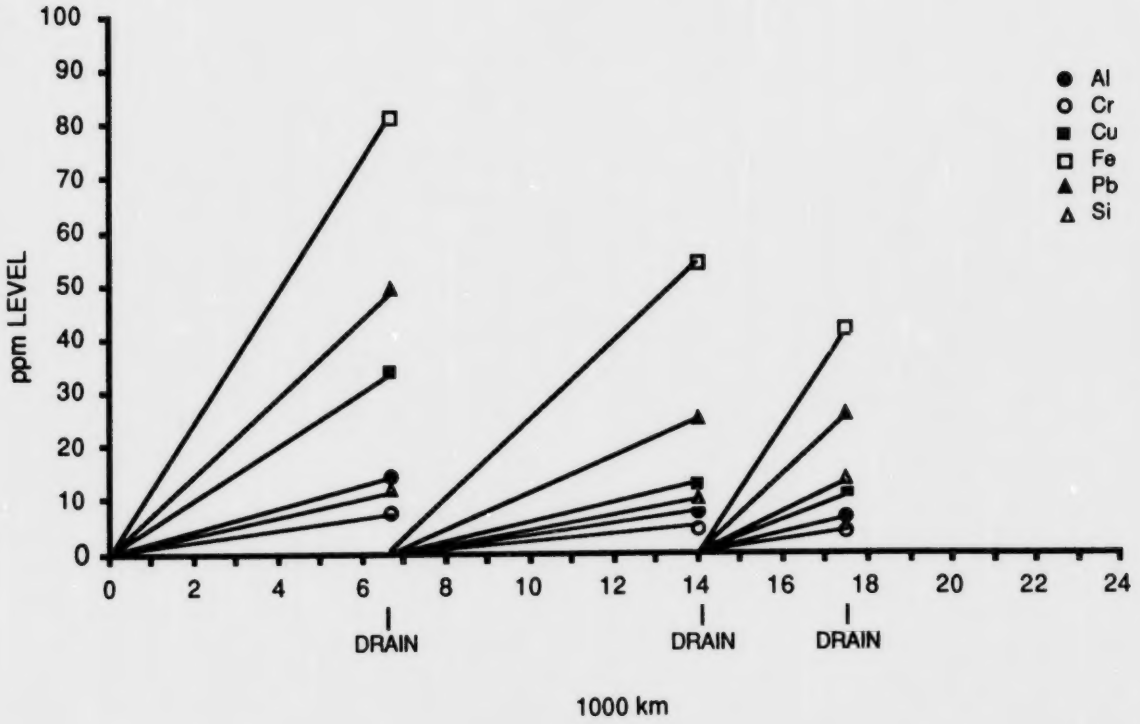


Figure 4/ Used-Oil Analysis – Car 342, Oil B

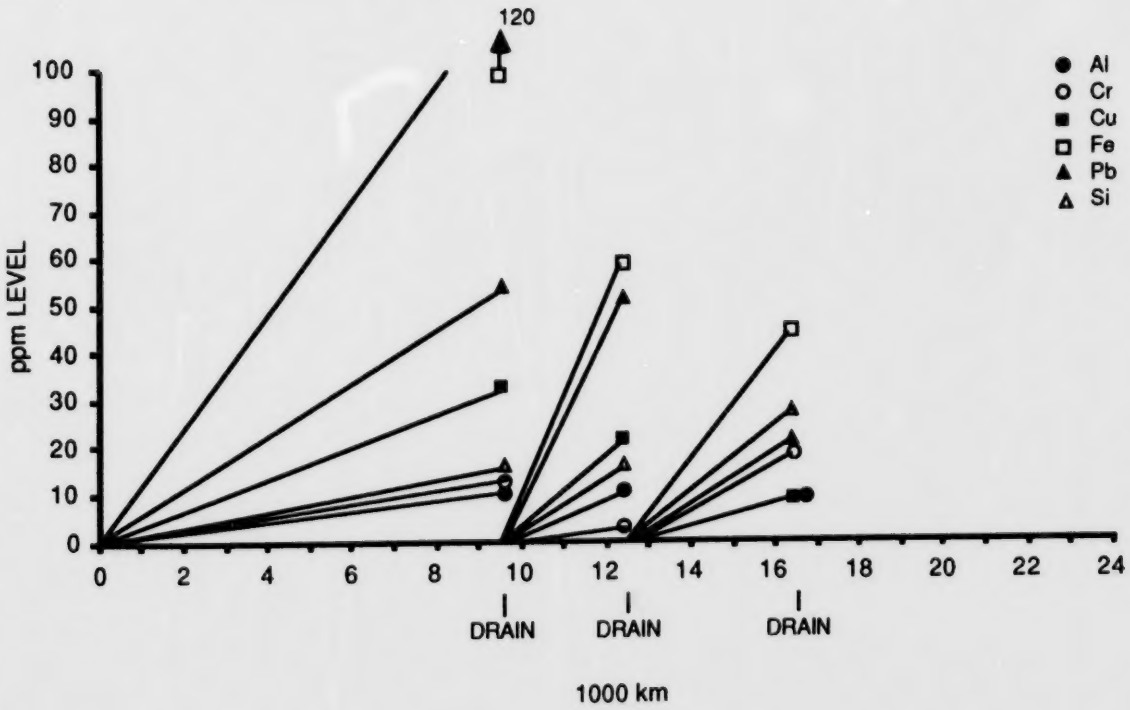


Figure 5/ Used-Oil Analysis – Car 343, Oil C

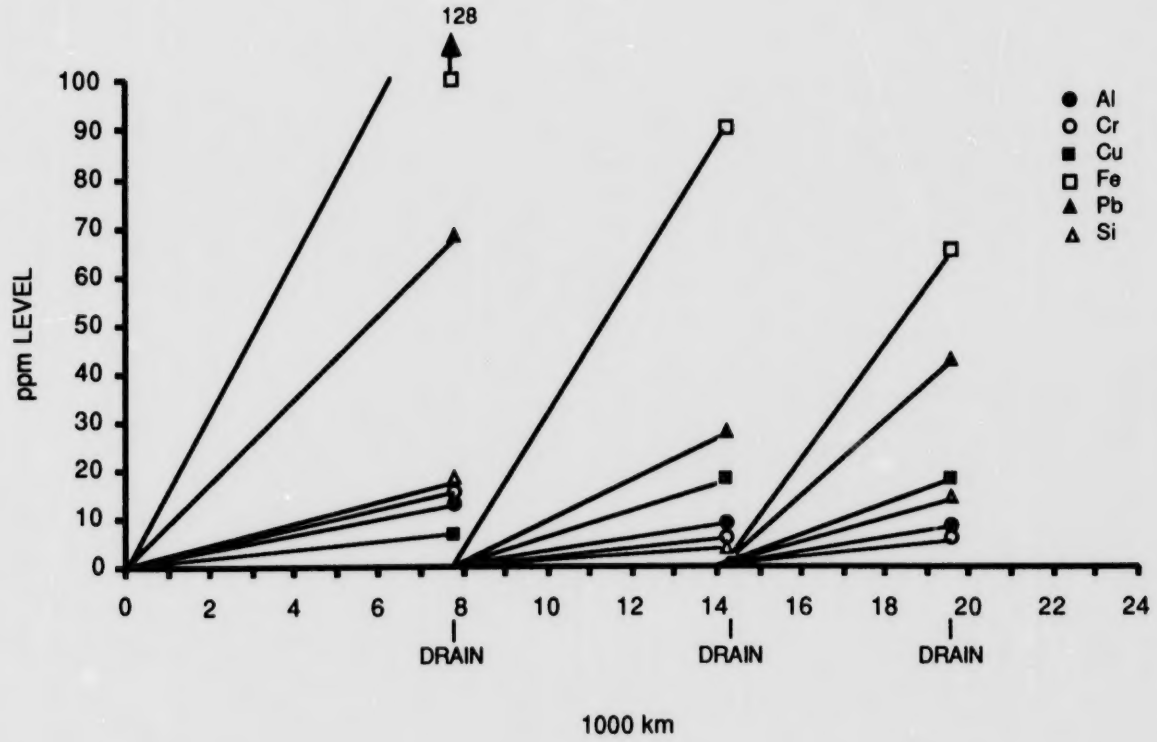


Figure 6/ Used-Oil Analysis – Car 344, Oil A

Oil A showed an approximate reduction in viscosity, at 100°C, of 1 centistoke (cSt); oil B showed a reduction of 1.5 cSt; and oil C a reduction of 0.5 cSt. These results are generally as expected, as only oil B used a viscosity index improper (VII). Oils A and C were blended in two narrow multi-grades with no VII. A VII was not used in oils A and C because intake system deposits could be produced due to an interaction between the VII and the methanol fuel.

Fuel dilution, as measured by the ASTM D-322 method, will not detect water-soluble fuels such as methanol. The three oils gave similar results, which are all quite low, ranging up to 1.0% by volume. This value would be representative of the amount of hydrocarbon fuel dilution, which was only 15% by volume of the fuel.

The total acid number (TAN), as measured by ASTM D-644, indicates the relative amount of acidic constituents in the used oil. The three oils increased by up to three numbers from new until drained.

The total base number (TBN), as measured by ASTM D-644 or by ASTM D-2896, indicates the relative amount of basic constituents in used oil. As the lubricant degrades, due to the neutralization of the acids produced from combustion, the TBN will drop. The TBN dropped by four to eight numbers with oil A and by approximately two numbers for oils B and C. This is similar to the results obtained in Phase 3 of this program.

As indicated in Appendix B, wear metals in the oil can be used to infer the condition of the engine at the time samples are taken.

Aluminum, in parts per million (ppm), was generally less than 15 ppm. The level was highest at the first or second drain (i.e., after car operation at low ambients) and then decreased with subsequent drains. Chromium levels were highest at the first or second drain of the test, decreasing with subsequent oil changes. Oil A gave levels up to 20 ppm, with oils B and C generally lower, at 10 ppm or less. Chromium level should indicate ring wear. The levels are higher than the Phase 2 normal-service cars.

Copper ranged up to 34 ppm and decreased as ambient temperatures increased. The copper would come from the top half of the number three main bearing. This bearing includes a thrust surface, with no overlay, and so would be a source of copper. The Phase 2 results were much higher.

The iron levels were usually higher than the five other metals which were measured. After the first one or two drains, the levels at each drain dropped. Oil B gave levels up to 70 to 80 ppm, whereas oils A and C ranged up to 120 ppm. Iron would indicate cylinder bore or camshaft wear. The levels were similar in magnitude to those found with the normal-service cars in Phase 2.

Lead levels ranged up to 70 ppm but were usually lower. Lead could come from the bearings or, possibly, the terneplate filler neck in the fuel tank. The lead levels in Phase 2 were much higher. This indicates that most of the terneplate was removed from the filler neck in Phase 2, allowing lower levels of lead to be present in the oil when drained. Again, the levels were highest in the first or second drain and dropped with subsequent drains.

Silicon ranged up to 36 ppm. Generally, oil C gave higher levels than A or B, particularly during the first or second drain. After these two drains, the level dropped generally to 10 or 15 ppm, which is what would be expected from contamination from ingested dirt. The higher initial levels, during the colder months, could be due to wear and/or corrosion of the engine block, the cylinder head, dirt in the fuel, or extraction of silicone from gasket materials. The first is most likely due to the effect being observed at lower ambient temperatures.

3.5/ Engine Ratings

The three Shell cars were dismantled at the end of the test and rated for sludge and varnish deposits, clogging, stuck components, intake valve deposits, and valve deposit weights.

Table 13 gives the valve deposit ratings and weights for the three cars and the average of the four normal-service cars in Phase 2. Table 14 gives the engine ratings, with the Phase 2 results for comparison. It should be noted that the average distance accumulation on the Phase 2 cars that were rated was 25 300 km, compared to 20 800 km in Phase 4.

The intake valve deposit ratings were all good. Oils A and C were similar to Phase 2, with oil B being slightly poorer. This rating does not include the valve face.

The intake valve deposit weights, which would include the deposit on the valve face, were less than in Phase 2. Oil B was highest, with oils A and C giving lower, similar results. All three oils had lower sulphated ash levels than in Phase 2; however, oil B used a VII. The use of VIIs has been known to give higher intake valve deposits with fuel-methanol.

Table 13/ Engine Valve Ratings

Oil Type	A	B	C		Phase 2
				3 Car	4 Car
Car No.	333	334	335	Avg.	Avg.
Intake Valve Deposits (10 = Clean)					
1	9.0	7.8	9.0	8.6	9.1
2	8.8	9.0	9.0	8.9	9.0
3	9.0	7.5	9.0	8.5	9.0
4	9.0	9.0	9.0	9.0	9.1
Average	8.9	8.3	9.0	8.7	9.0
Intake Valve Deposit wt., g					
1	0.259	0.665	0.124	0.349	0.342
2	0.195	0.139	0.221	0.185	0.231
3	0.242	0.319	0.228	0.263	0.294
4	0.179	0.214	0.178	0.190	0.617
Average	0.219	0.334	0.188	0.247	0.371
Exhaust Valve Deposit wt., g					
1	0.244	0.326	0.158	0.243	0.671
2	0.366	0.160	0.221	0.249	0.333
3	0.337	0.178	0.235	0.250	0.410
4	0.234	0.213	0.268	0.238	0.499
Average	0.295	0.219	0.221	0.245	0.478
Δkm	20 770	22 388	19 111	20 756	25 300

Table 14/ Engine Ratings

Oil Type	A	B	C		Phase 2
Car No.	333	334	335	3 Car Avg.	4 Car Avg.
Sludge Deposits					
Rocker Arm Cover	9.80	9.81	9.73	9.78	9.79
Front Seal Housing	9.75	9.75	9.75	9.75	9.86
Oil Pan	9.67	9.73	9.67	9.69	9.71
Valve Deck	9.69	9.67	9.71	9.69	9.82
Block Underside	9.67	9.73	9.67	9.69	9.75
Average	9.72	9.74	9.71	9.72	9.79
Varnish Deposits					
Piston Skirts	9.00	9.11	9.21	9.11	9.27
Rocker Arm Cover	8.22	8.37	8.90	8.50	9.03
Cylinder Wall	9.34	9.40	8.73	9.16	9.22
Oil Pan	8.29	8.72	8.31	8.44	8.91
Average	8.71	8.90	8.79	8.80	9.10
Clogging					
Oil Ring, %	0	0	0	0	0
Oil Screen, %	0	0	0	0	0
Stuck Comp. Rings, no.	0	0	0	0	0
Stuck Oil Rings, no.	0	0	0	0	0
Stuck Lash Adj. Bodies, no.	0	0	0	0	0
Stuck Lash Adj. Plungers, no.	0	0	0	0	0
Δkm	20 770	22 388	19 111	20 756	25 300

This seems to be reflected in the results.

The exhaust valve deposit weights were much lower than in Phase 2. All three oils gave similar deposit weights. The deposits were also not as hard as those in Phase 2. This reduction in amount and hardness seems to parallel the reduction in sulphated ash level from 2.9% by mass in Phase 2 to 1.5 to 1.6% by mass with the present three oils.

The sludge ratings were all good and equivalent to the Phase 2 results. It appears that cars operated on fuel-methanol exhibit low sludge formation tendencies.

The engine varnish ratings varied between 8.7 and 8.9, compared to 9.1 with Phase 2. Varnish is related to temperature and hydrocarbon composition -- more olefinic components give higher varnish ratings. This could be caused by higher operating temperatures or the switch from M90 to M85 fuel. The levels are still quite acceptable compared to results with gasoline-fuelled engines (see Appendix E).

No clogged or stuck components were found in the three cars, which is identical to the Phase 2 results.

3.6/ Engine Wear Results

Table 15 details the dimensional changes in the three Shell cars during the test. Generally, the Phase 2 results were higher than any of the three test oils. Cylinder bore wear was low, typically 2.5 μm. The only other significant dimensional changes occurred with ring gap growth and camshaft lobe height. Ring gap growth was lower than in Phase 2. Oil B gave the lowest results, with oils A and C being similar. Camshaft lobe height measurements were lower or equal to Phase 2 for all but the exhaust lobes with car 335, which used oil C.

Car 335 showed excessive wear of the exhaust lobes for cylinders 2, 3, and 4, with wear in the 12.7 to 20.3 μm range. Car 343, at 50 000 km (as discussed earlier), also showed excessive wear of the exhaust lobes on cylinders 2 and 3 and catastrophic wear on the cylinder 4 exhaust lobe. Car 343 operated on oil C for 12 446 km before failure. Prior to that oil, the car operated for the initial 37 554 km on the Phase 2 oil. The average oil change interval for this car was 6250 km for the first 50 000 km (eight oil changes), as opposed to the recommendation of 5000 km oil drains.

Results with an equivalent 1983 gasoline Ford Escort powered by a similar engine are given in Appendix F. This car was operated on an SF quality

Table 15/ Engine Wear Results -- Dimensional

Oil Type	A	B	C	3 Car	Phase 2 2 Car
Car No.	333	334	335	Avg.	Avg.
Cyl. Dia., Long, μm	2.5	2.5	2.5	2.5	10.2
Trans., μm	2.5	0.0	5.1	2.5	15.2
Piston Skirt Dia., μm	2.5	7.6	7.6	5.1	12.7
Ring Gap Growth, (top) μm	38.1	20.3	43.2	33.0	88.9
(middle) μm	50.8	33.0	76.2	53.3	88.9
Ring Side Clearance, (top) μm	2.5	0.0	2.5	2.5	12.7
(middle) μm	2.5	0.0	0.0	0.0	7.6
Valve Stem Dia., (I) μm	2.5	0.0	0.0	0.0	0.0
(E) μm	2.5	0.0	2.5	2.5	0.0
Valve Guide Dia., (I) μm	2.5	2.5	2.5	2.5	12.7
(E) μm	2.5	0.0	0.0	0.0	7.6
Camshaft Lobe (E) μm	5.1	5.1	127.0	45.7	17.8
(I) μm	2.5	7.6	20.3	10.2	17.8
Valve Tip Ht., (I) μm	0.0	15.2	2.5	5.1	5.1
(E) μm	10.2	17.8	20.3	15.2	2.5
Journal Con. Rod, μm	-(1)	-(1)	5.1	-	5.1
Mains, μm	-(1)	-(1)	0.0	-	2.5

(1)Initial measurements not taken; however, final measurements indicate wear levels in the same order of magnitude as in Phase 2 or car 335.

10W30 grade oil. Higher than expected wear, similar in appearance to that on cars 335 and 343, was apparent on the exhaust lobes for cylinders 3 and 4 (25.4 and 22.9 μm) after 37 228 km of operation. A normal drain period of 12 000 km (which is recommended by the manufacturer for this engine) was used.

Table 16 lists test data for oil C in the Sequence III-D and V-D engine tests. The cam and lifter wear in the Sequence III-D are much lower than the test limits; the cam wear in the Sequence V-D is also much lower than the test limit. The cam wear problems appear to be related to the specific cams used in these cars. Based on these test results, test oil C gave more than adequate valve train wear protection.

Table 17 gives the changes in weight of the various pre-measured components. In general, the three oils gave lower wear than the Phase 2 oil, with the following exceptions: top ring weight loss with oils A and B, rod and main bearing weight loss with oil C, and rocker arm pivot weight loss with oils A and B.

3.7/ Engine Durability

In total, the three candidate oils are equivalent. The three oils are superior to the Phase 2 oil.

Indications, from used-oil analysis, are that the major portion of the wear with fuel-methanol occurs at lower ambient temperatures.

The wear with these cars and test oils was acceptable. However, cam and lifter wear, ring wear, and to a small extent, bore wear are higher than would be expected with gasoline, which also indicates more wear.

The varnish and sludge levels with fuel-methanol are good. The level of valve deposits with these three oils is better than the Phase 2 oil.

Finally, the nominal drain period used with these methanol-fuelled cars was 5000 km. The use of longer drain periods appeared to increase levels of metal wear, which indicates more wear was occurring. Similar gasoline engines would use a drain period of 12 000 km. The use of fuel-methanol then causes increased wear even with the use of drain periods less than one-half that recommended for similar gasoline engines, in colder climates.

Table 16/ Sequence III-D and V-D Test Results for Oil C

Sequence IIID Results	Results	Test Limits
Piston Varnish, Average	9.2	9.2
Oil Ring Land Deposits, Average	7.6	4.8
Engine Sludge, Average	9.6	9.2
Viscosity Inc. @ 64 h, %	46	375
Cam + Lifter Wear		
Maximum μm	79	203
Average μm	41	102
Ring Sticking, No.	2	0
Lifter Sticking, No.	0	0
Scuffing, Cam and Lifter, No.	0	0
Oil Consumption, USQT, maximum	2.75	6.38
Sequence V-D Results		
Engine Sludge, Average	8.6	9.4
Engine Varnish, Average	7.9	6.6
Piston Skirt Varnish, Average	7.5	6.7
Cam Wear		
Maximum μm	20	64
Average μm	15	25
Oil Ring Clogging, %	0	10
Oil Screen Clogging, %	25	7.5
Comp. Ring sticking, No.	2	0

Underlined values exceed test limits.

Table 17/ Engine Wear Results -- Weight

Oil Type	A	B	C	3 Car	Phase 2 2 Car
Car No.	333	334	335	Avg.	Avg.
Ring wt. (top) g	0.0836	0.0614	0.0497	0.0649	0.0458
Cleaned Loss (middle) g	0.0209	0.0193	0.0161	0.0188	0.0213
Rod Bearing wt. Loss (top) g	0.0081	0.0106	0.0229	0.0139	0.0186
(btm) g	0.0031	0.0041	0.0079	0.0050	0.0057
(both) g	0.0112	0.0147	0.0308	0.0189	0.0243
Main Bearing wt. Loss (top) g	0.0537	0.0216	0.0698	0.0484	0.0740
(btm) g	0.0113	0.0147	0.0219	0.0160	0.0116
(both) g	0.0650	0.0363	0.0917	0.0644	0.0856
Rocker Arm wt. Loss (I) g	-0.0079	-0.0111	-0.0015	-0.0030	-0.0093
(E) g	-0.0097	-0.0039	+0.0004	-0.0044	-0.0072
Rocker Arm Pivot wt. Loss (I) g	0.1166	0.1559	+0.0090	0.0938	+0.0064
(E) g	0.1620	0.0992	-0.0061	0.0850	-0.0037
Δkm	20 770	22 388	19 111	20 756	25 300

3.8/ Comparison with Prior Results

Phase 3 of this program [9] concerned testing of six methanol-fuelled Ford Escorts under short-trip operation for approximately nine months. The same three test oils were used in Phases 3 and 4.

The results indicated that the three test oils gave low levels of sludge varnish and valve deposits. Some rusting of components was evident. Less cylinder bore wear, less ring wear, but similar cam wear were present in the Phase 4 normal-service cars compared to the Phase 3 short-trip cars.

In Phase 2, there were also short-trip components with four test cars. The test oil gave similar results to the three Phase 3 oils. The three test oils used in Phases 3 and 4 appear to give a similar level oil performance in both short-trip and normal-service operations.

4/ CONCLUSIONS

1/ The three oils are equivalent and better than the Phase 2 oil, in normal-service cars.

2/ All three oils gave low sludge, varnish, and valve deposits.

3/ The major areas of wear with these methanol-fuelled engines in normal service are cam and lifter wear, ring wear, and to a lesser extent, cylinder bore wear.

4/ As ambient temperature decreases, wear increases with methanol-fuelled engines.

5/ Energy consumption, under summer conditions, is similar to that obtainable with equivalent gasoline-fuelled cars.

6/ Energy consumption, over-the-road, during winter was 25 to 30% higher than during summer.

5/ RECOMMENDATIONS

1/ A much longer test with gasoline control vehicles is required to address the concern that engine life with fuel-methanol is reduced over that with gasoline, in cold climates.

2/ Improvements in engine performance at colder temperatures are required to ensure fuel-methanol is a competitive fuel in regions with cold climates, such as Canada. The areas requiring improvement include energy consumption, engine durability, cold startability, and driveability.

6/ REFERENCES

[1] Mitchell, D.K., "Straight Methanol and Vehicle Evaluation -- Phase 1, The Cold Weather Performance of a Variety of Methanol Fuel Blends," Ontario Ministry of Transportation and Communications, AF-84-03, April 1984.

[2] Chaibongsai, S., et al, "Development of an Engine Screening Test to Study the Effect of Methanol Fuel on Crankcase Oils," SAE 830240, Warrendale, Pa., USA, 1983.

[3] Chamberlain, W.B., and Brandow, W.C., "Lubrication Experience in Methanol-Fuelled Engines under Short-Trip Service Conditions," SAE 831701, Warrendale, Pa., USA, 1983.

[4] Ryan, T.W., III, et al, "The Mechanisms Leading to Increased Cylinder Bore and Ringwear in Methanol-Fuelled S.I. Engines," SAE 811200, Warrendale, Pa., USA, 1981.

[5] Marbach, H.W., et al, "The Effects of Lubricant Composition on S.I. Engine Wear with Alcohol Fuels," SAE 831702, Warrendale, Pa., USA, 1983.

[6] Nichols, R.J., "Field Experience with Methanol Vehicles: Future Design Considerations," Co-ordinating European Council, Wolfsburg, Germany, June 1985.

[7] Krumm, H., et al, "Lubrication of Spark Ignition Engines Running on Alcohol Containing Fuels," 5th International Symposium on Alcohol Fuels, Aukland, New Zealand, May 1982.

[8] Mitchell, D.K., "Straight Methanol and Vehicle Evaluation -- Phase 2, Durability of a Fleet of Methanol-Fuelled Vehicles," Ontario Ministry of Transportation and Communications, AF-85-03, August 1985.

[9] Mitchell, D.K., "Straight Methanol and Vehicle Evaluation -- Phase 3, Further Durability Testing of a Fleet of Methanol-Fuelled Vehicles," Ontario Ministry of Transportation and Communications, AF-86-07, 1986.

[10] "Fuel Consumption Guide," Transport Canada Road Safety Branch, 1983 Edition.

APPENDIX A/ TEST CAR IDENTIFICATION

APPENDIX A/ TEST CAR IDENTIFICATION

Test Car Number	License Plate Number	Type	Colour	VIN
333	VAB 233	4 dr	Red	1FABP1477DW243329
334	VAB 234	4 dr	Lt. Blue	1FABP1473DW243330
335	VAB 235	4 dr	Tan	1FABP1479DW243333
342	TML 613	Wgn	Tan	1FABP1075DW243334
343	TMM 611	Wgn	Maroon	1FABP1075DW243335
344	TMK 611	4 dr	Red	1FABP1070DW242220

APPENDIX B/ USED-OIL ANALYSIS RESULT INTERPRETATION

APPENDIX B/ USED-OIL ANALYSIS RESULT INTERPRETATION

Test	Results "Warning Limits"	"Median"	"90%ile"	"Typical"	"Range"	Components
TBN	50% drop	-	-	-		
Viscosity @ 100°C	25% drop	-	-	-		
Pentane Insols., % by mass	>1.5	-	-	-		
Al, ppm	>40	19	15	-	15-40	pistons
Cr, ppm	>40	6.4	-	-	5-30	rings
Cu, ppm	>40	22	35	-	5-40	bearings, bushings
Fe, ppm	>100	47	75	-	40-200	cylinders
Pb, ppm	>40	-	-	-	-	bearings
Si, ppm	>20	18	17	20	5-25	dirt
Source	1	2	3	4	5	

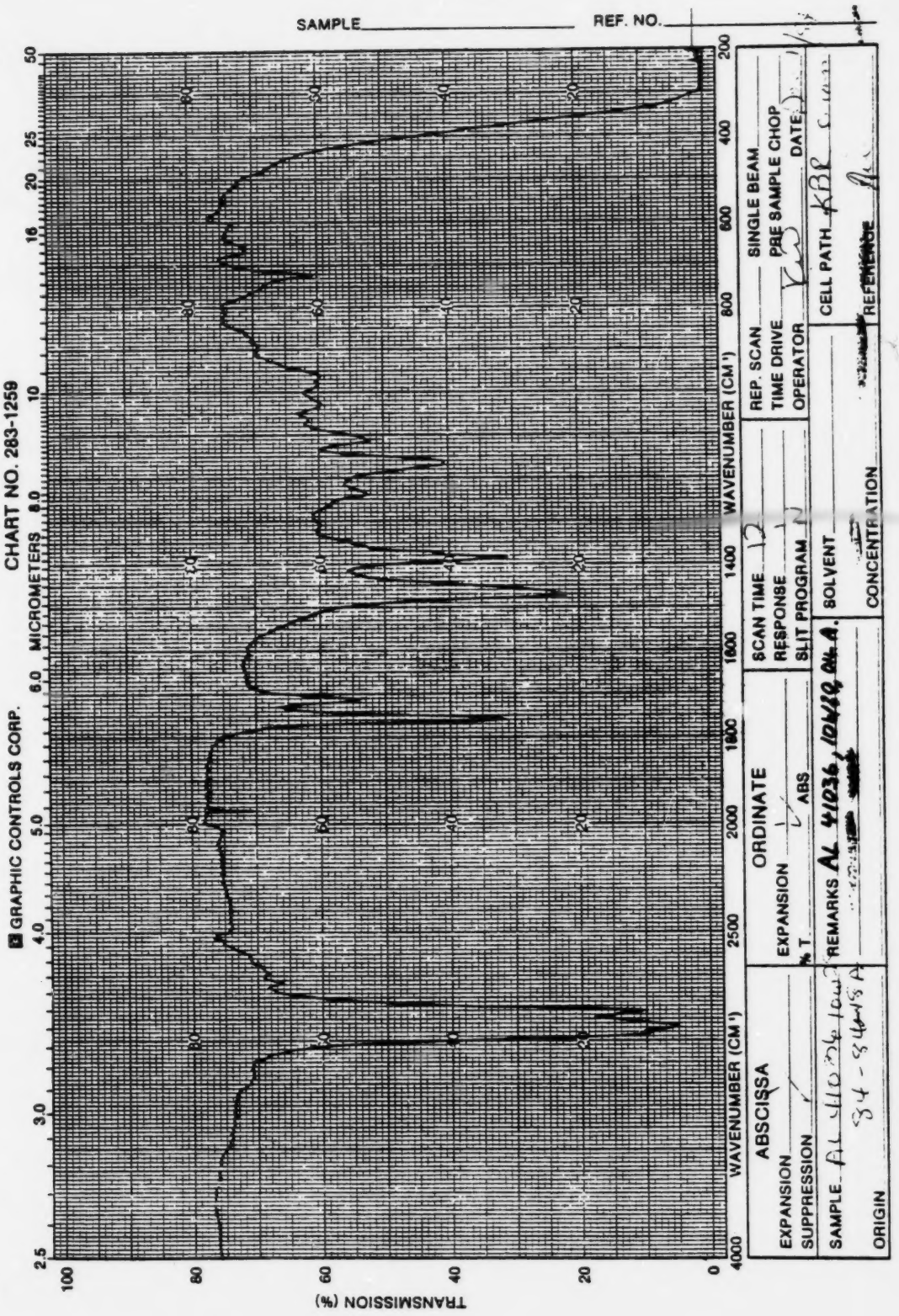
- All above data refer to used oil condition at drain.

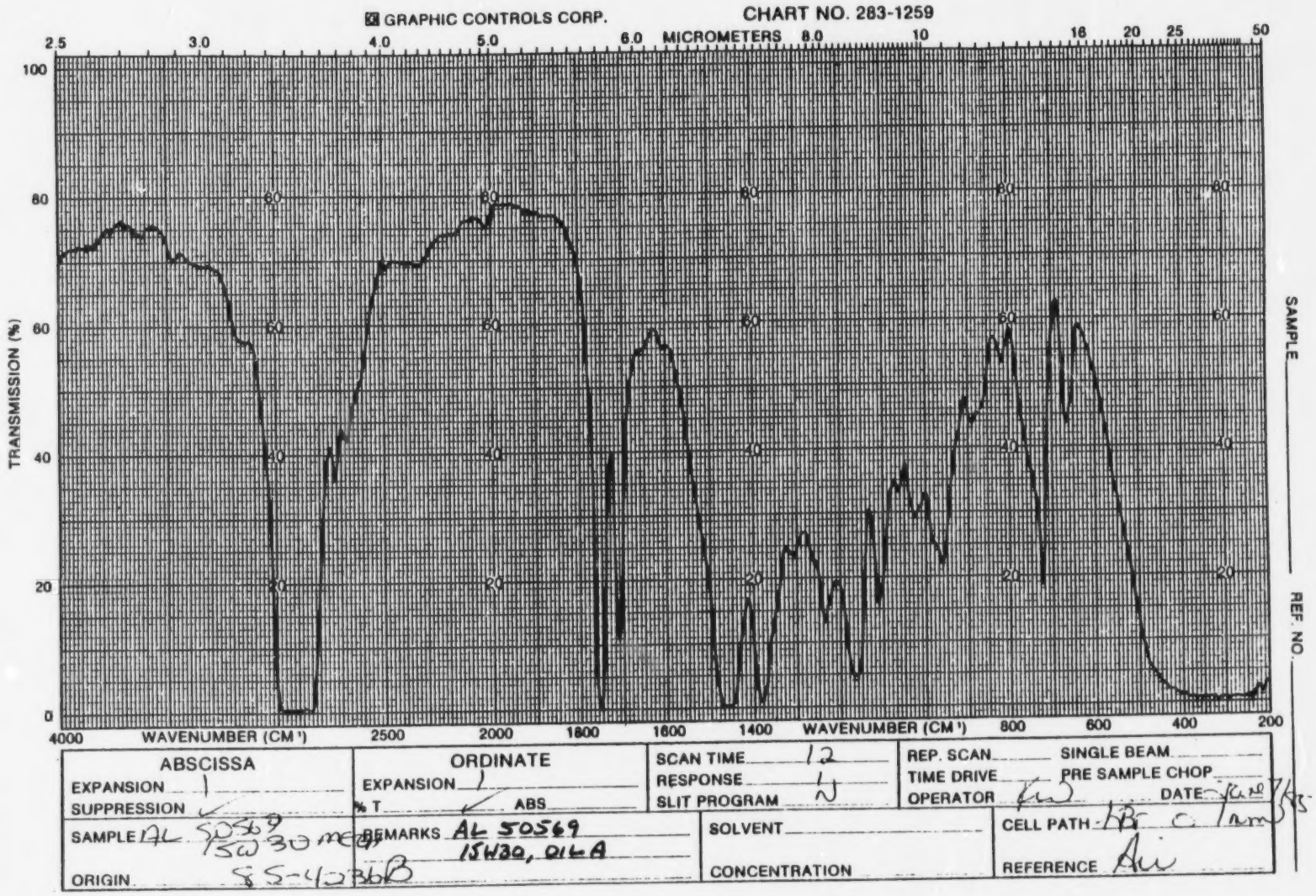
Sources 1/ "Testing Used Engine Oils," Chevron Research Co., 1983
2/ SAE Paper 77-642 (on diesel engines)
3/ SAE Paper 73-745 (on diesel engines)
4/ Fuels and Lubes Magazine, Sept./Oct., 1980
5/ SAE Paper 77-85 (on automobile engines)

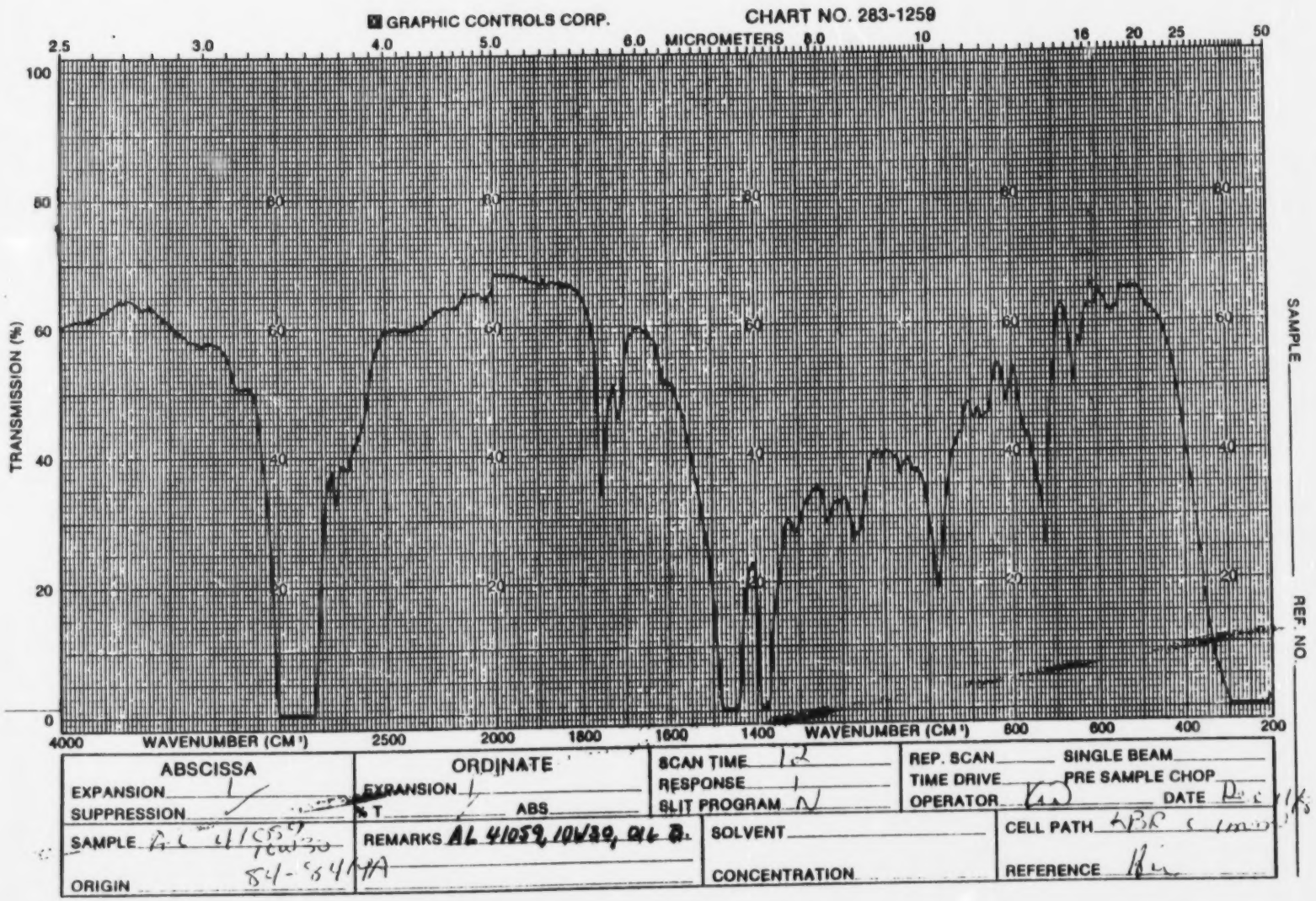
APPENDIX C/ NEW OIL INFRARED SCANS

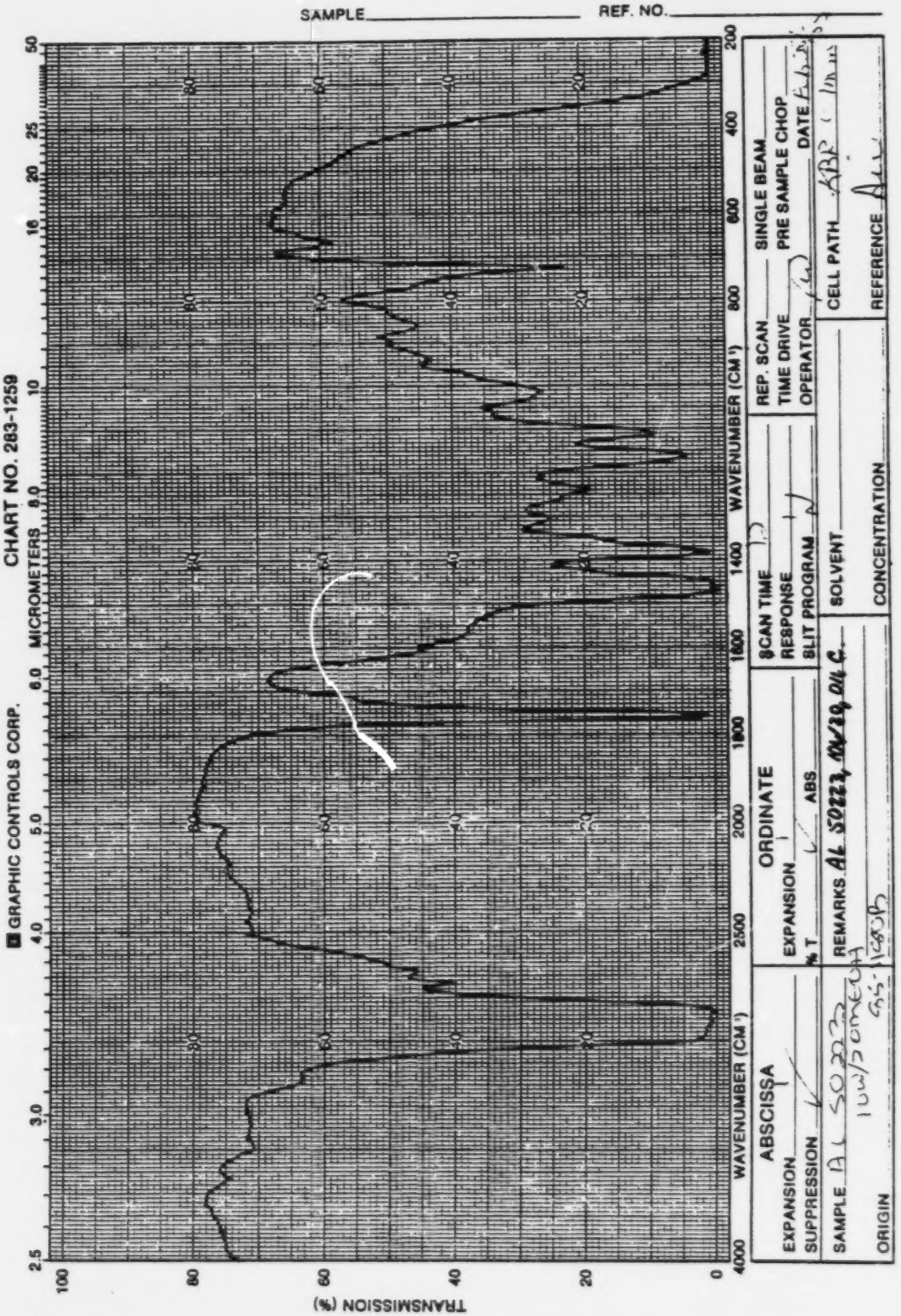
APPENDIX C/ NEW OIL INFRARED SCANS

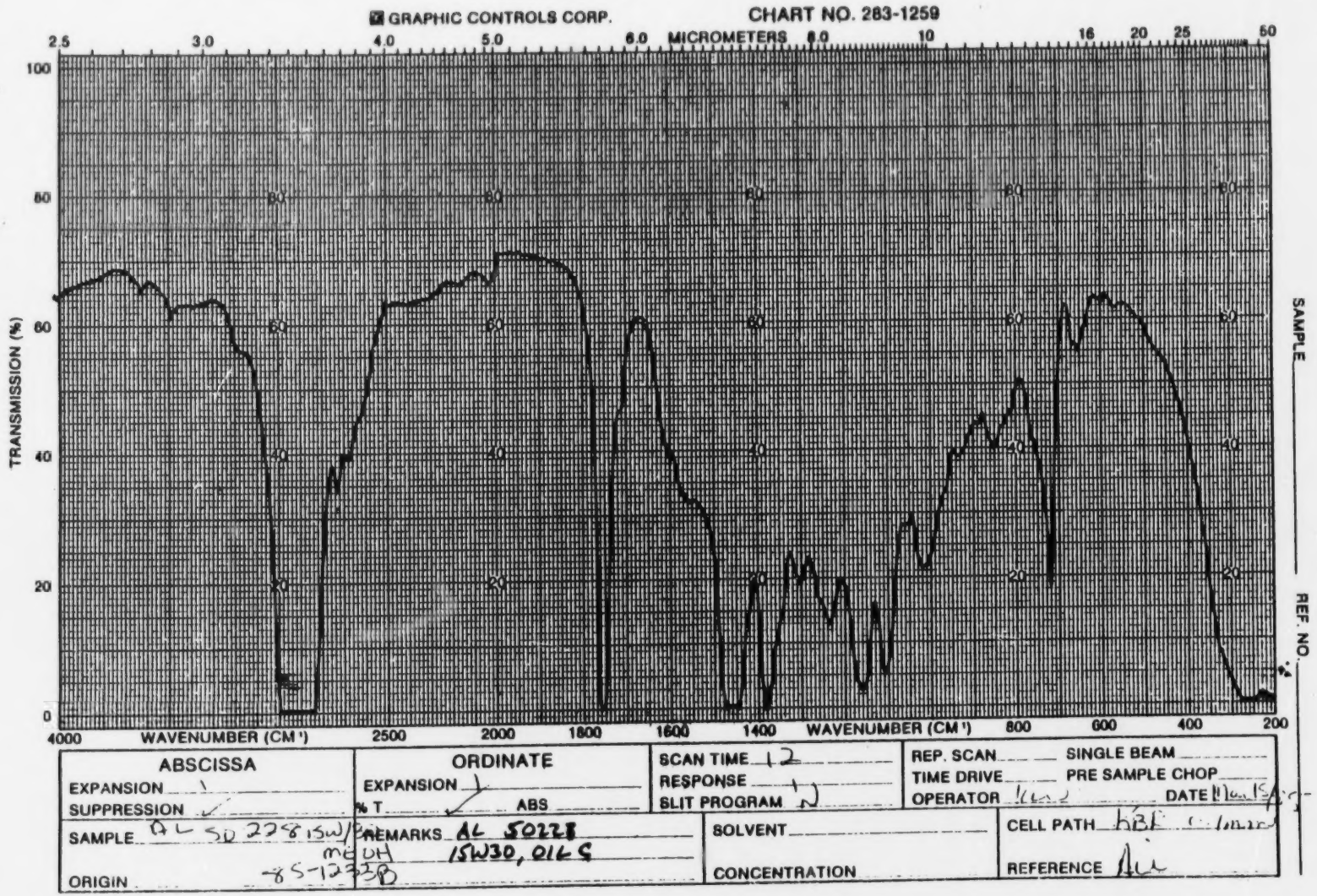
Oil Type	Page
Oil A - 10W20	46
Oil A - 15W30	47
Oil B - 10W30	48
Oil C - 10W20	49
Oil C - 15W30	50


SAMPLE
REF. NO.
GRAPHIC CONTROLS CORP.
CHART NO. 283-1259
MICROMETERS
WAVENUMBER (CM⁻¹)
TRANSMISSION (%)
ABSCISSA
EXPANSION
SUPPRESSION
ORDINATE
EXPANSION
% T
ABS
SCAN TIME
RESPONSE
SLIT PROGRAM
REP. SCAN
TIME DRIVE
OPERATOR
SINGLE BEAM
PRE SAMPLE CHOP
DATE
CELL PATH
SOLVENT
CONCENTRATION
REFERENCE
REMARKS
ORIGIN


GRAPHIC CONTROLS CORP.
CHART NO. 283-1259
2.5 3.0 4.0 5.0 6.0 MICROMETERS 8.0 10 16 20 25 50
100 80 60 40 20 0
TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF. NO.
ABSCISSA
EXPANSION 1
SUPPRESSION
ORDINATE
EXPANSION 1
% T ABS
SCAN TIME 12
RESPONSE N
SLIT PROGRAM
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR DATE
SAMPLE AL 50569 15W30 neat
ORIGIN S5-4-3B6B
REMARKS AL 50569 15W30, OIL A
SOLVENT
CONCENTRATION
CELL PATH
REFERENCE Air


GRAPHIC CONTROLS CORP.
CHART NO. 283-1259
2.5 3.0 4.0 5.0 6.0 MICROMETERS 8.0 10 16 20 25 50
100 80 60 40 20 0
TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF. NO.
ABSCISSA
EXPANSION 1
SUPPRESSION
ORDINATE
EXPANSION 1
% T ABS
SCAN TIME 12
RESPONSE 1
SLIT PROGRAM N
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR DATE
SAMPLE
ORIGIN
REMARKS AL 41059, 10/30, Qt B.
SOLVENT
CONCENTRATION
CELL PATH KBr c liquid
REFERENCE Air

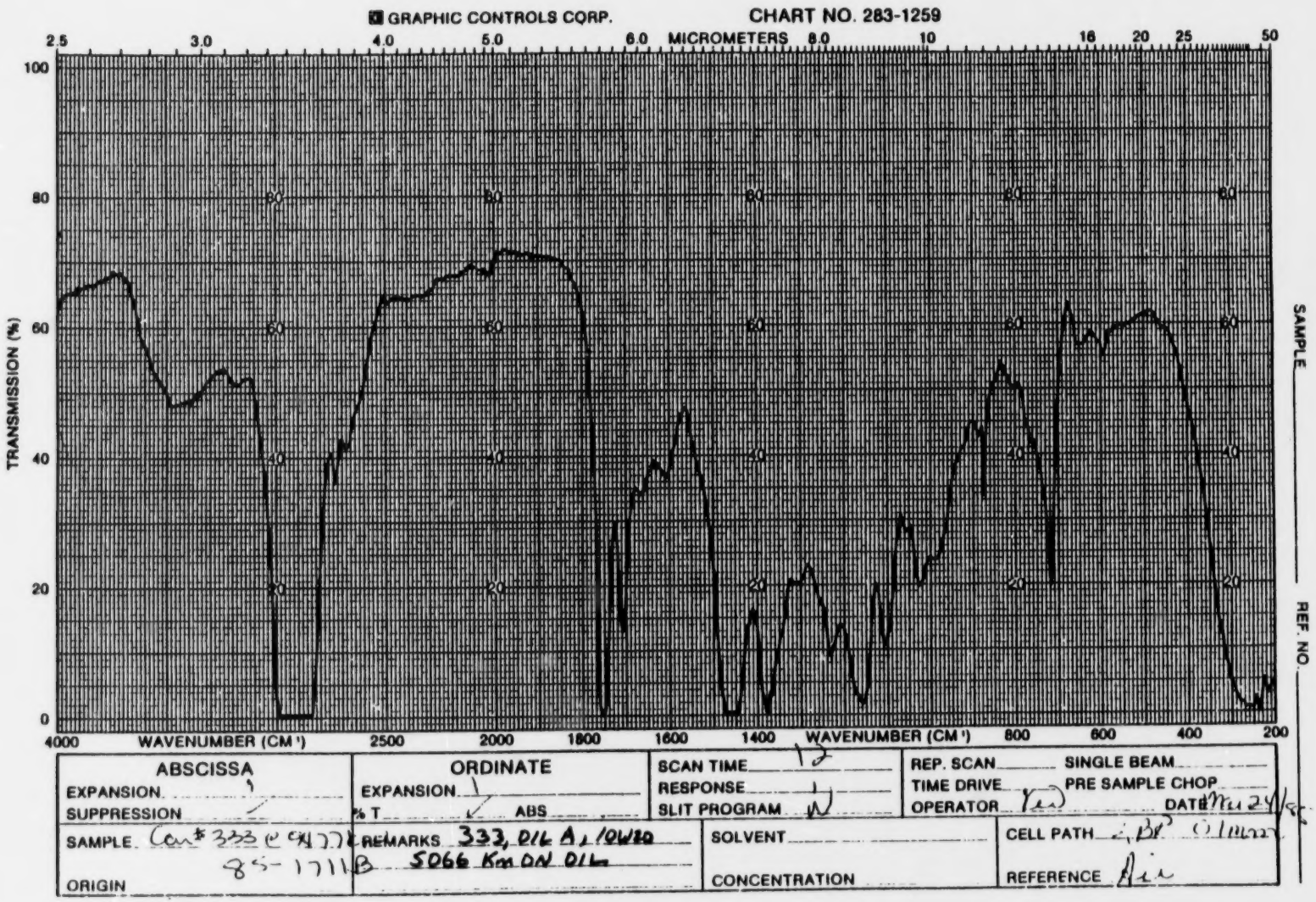

SAMPLE
REF. NO.
GRAPHIC CONTROLS CORP.
CHART NO. 283-1259
MICROMETERS
WAVENUMBER (CM⁻¹)
TRANSMISSION (%)
ABSCISSA
EXPANSION
SUPPRESSION
ORIGIN
ORDINATE
EXPANSION
% T
ABS
REMARKS
SCAN TIME
RESPONSE
SLIT PROGRAM
REP. SCAN
TIME DRIVE
OPERATOR
SINGLE BEAM
PRE SAMPLE CHOP
DATE
CELL PATH
SOLVENT
CONCENTRATION
REFERENCE

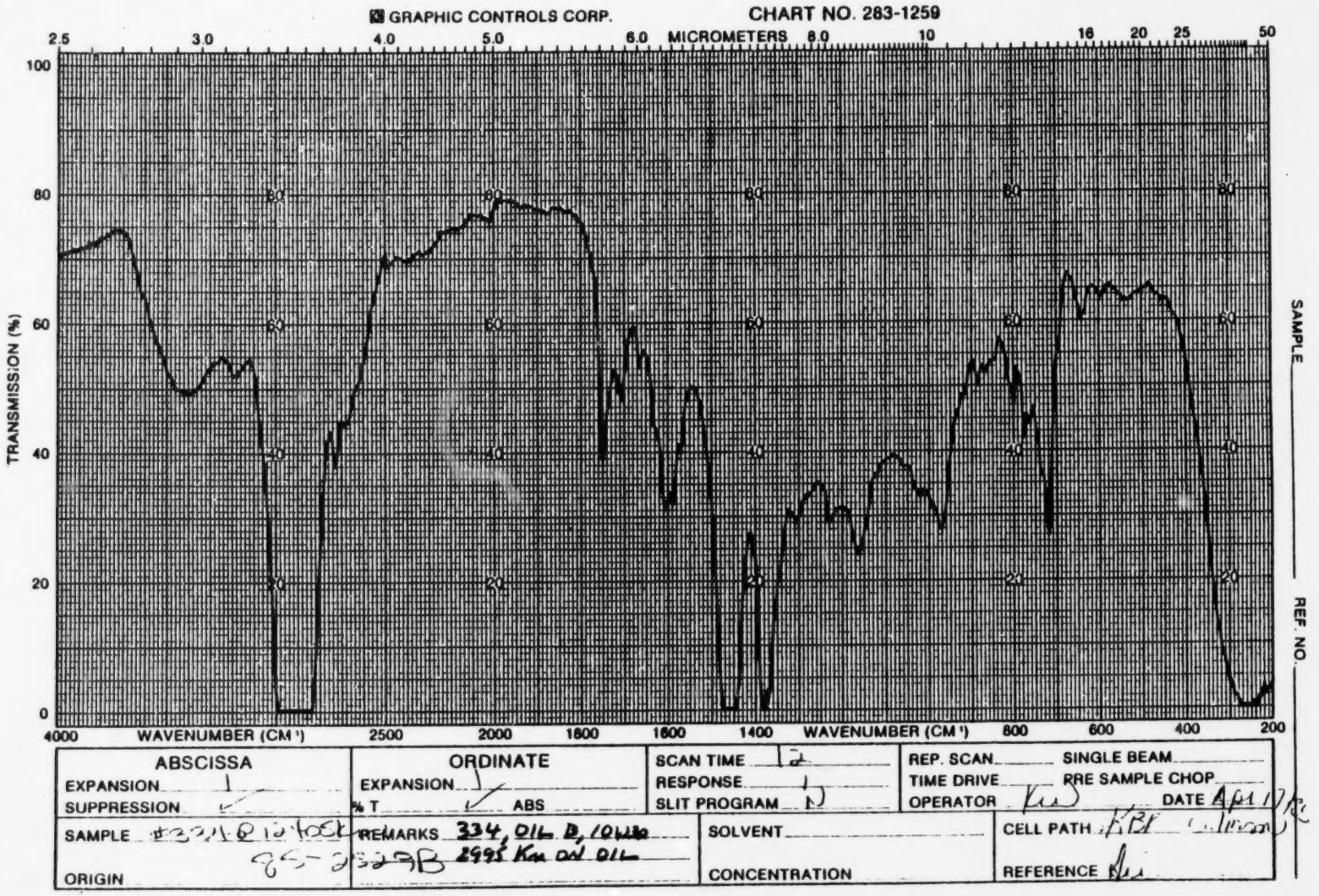

GRAPHIC CONTROLS CORP.
CHART NO. 283-1259
2.5 3.0 4.0 5.0 6.0 MICROMETERS 8.0 10 16 20 25 50
100
80
60
40
20
0
TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF. NO.
ABSCISSA
EXPANSION 1
SUPPRESSION ✓
ORDINATE
EXPANSION 1
% T ✓ ABS
SCAN TIME 12
RESPONSE 1
SLIT PROGRAM N
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR Wm DATE 11 Jan 85
SAMPLE AL SD 2258 15W/ MEUH
ORIGIN -85-1233B
REMARKS AL 50228 15W30, 01L S
SOLVENT
CONCENTRATION
CELL PATH KBr
REFERENCE Air

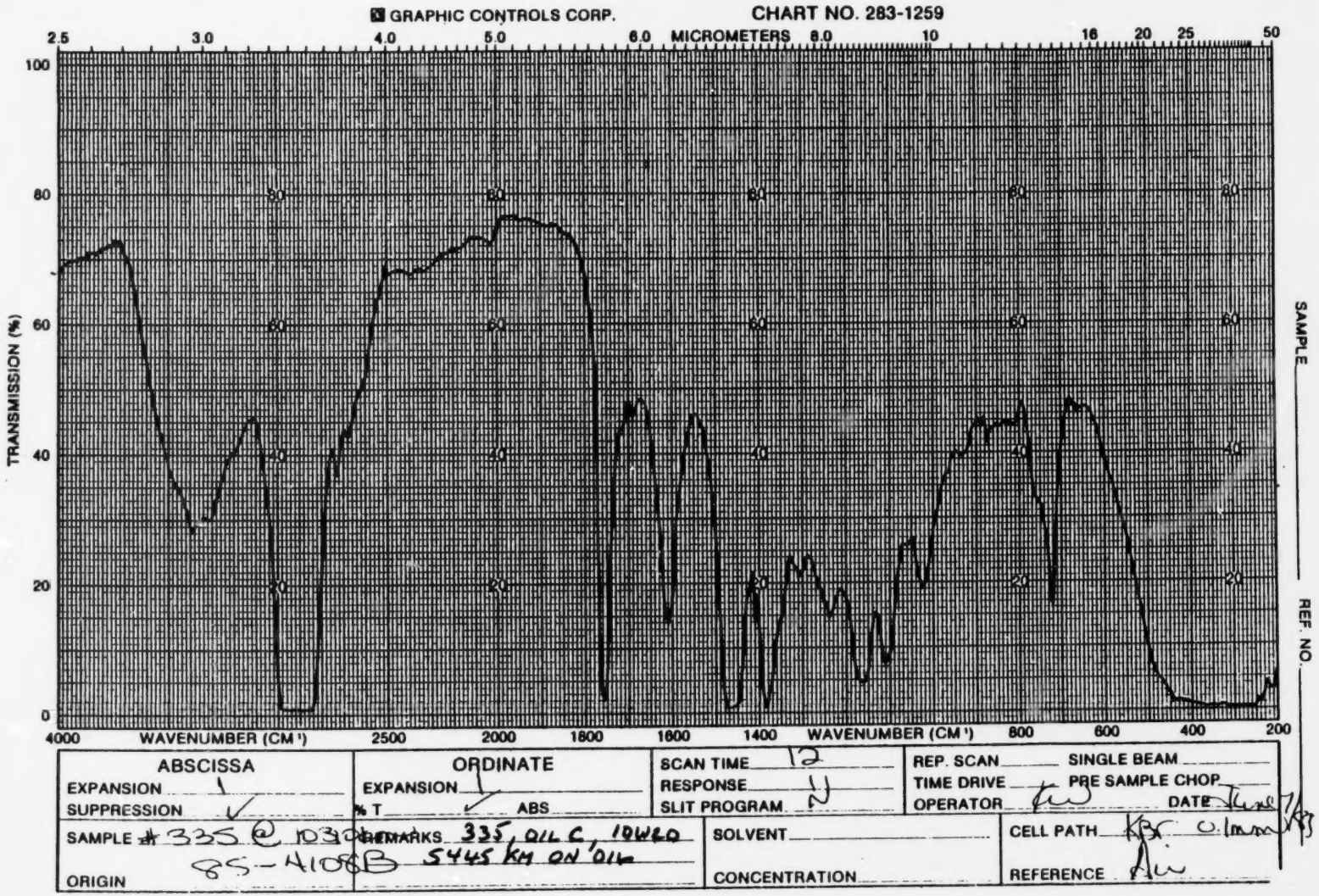
APPENDIX D/ SELECTED USED-OIL INFRARED SCANS

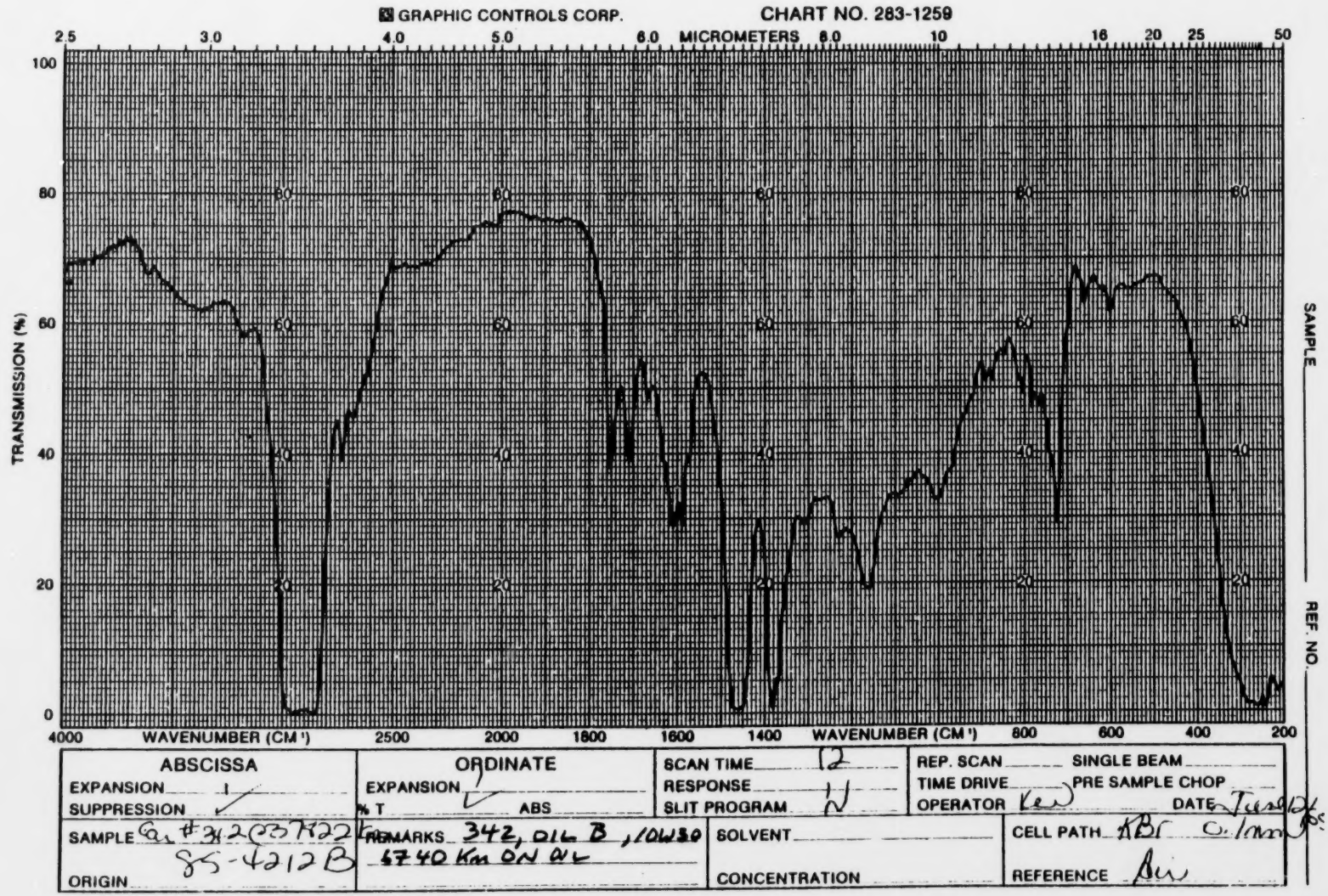
APPENDIX D/ SELECTED USED-OIL INFRARED SCANS

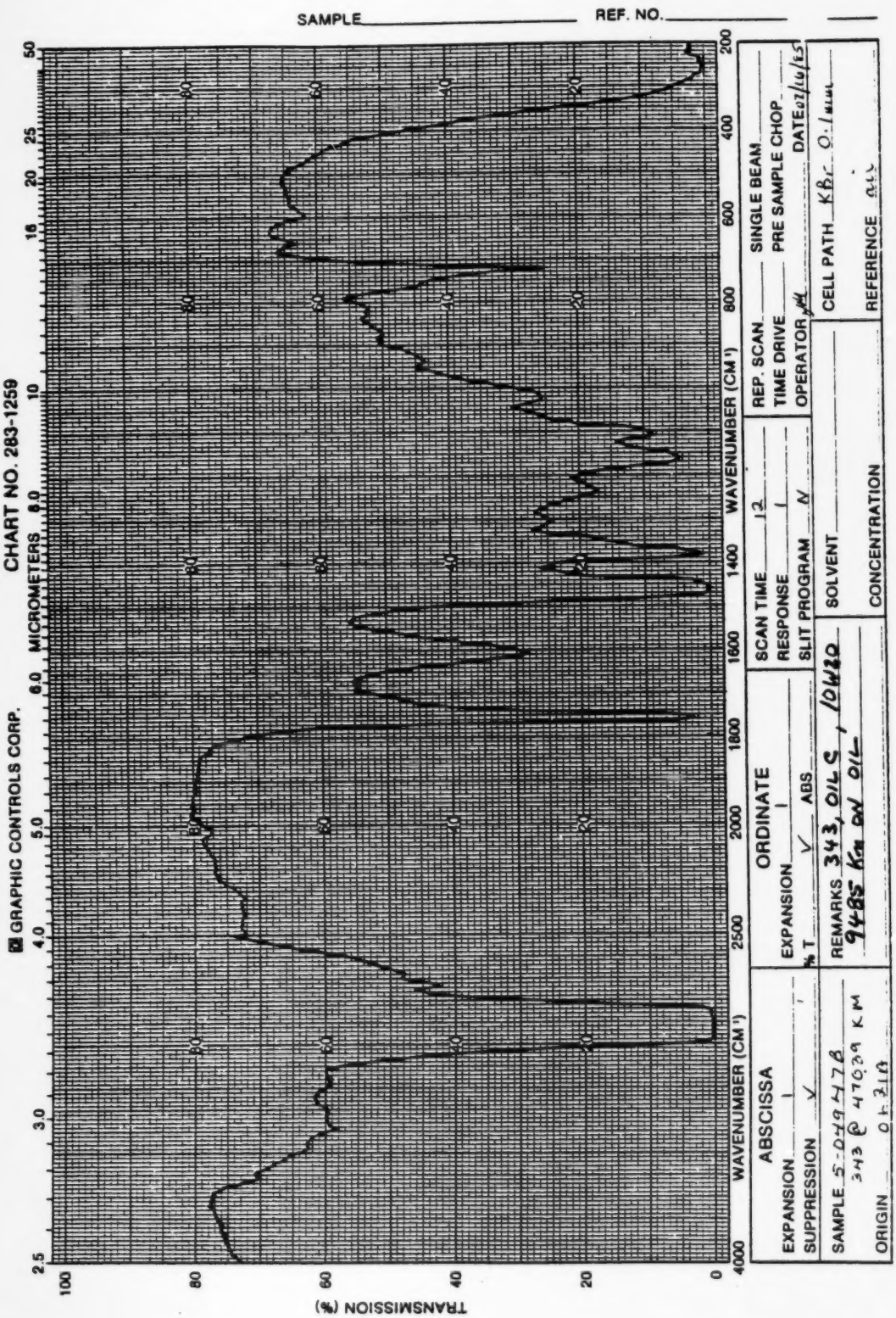
Details	Page
Car 333, Oil A, 5066 km on oil	53
334, Oil B, 2995 km on oil	54
335, Oil C, 5445 km on oil	55
342, Oil B, 6740 km on oil	56
343, Oil C, 9485 km on oil	57
344, Oil A, 7826 km on oil	58

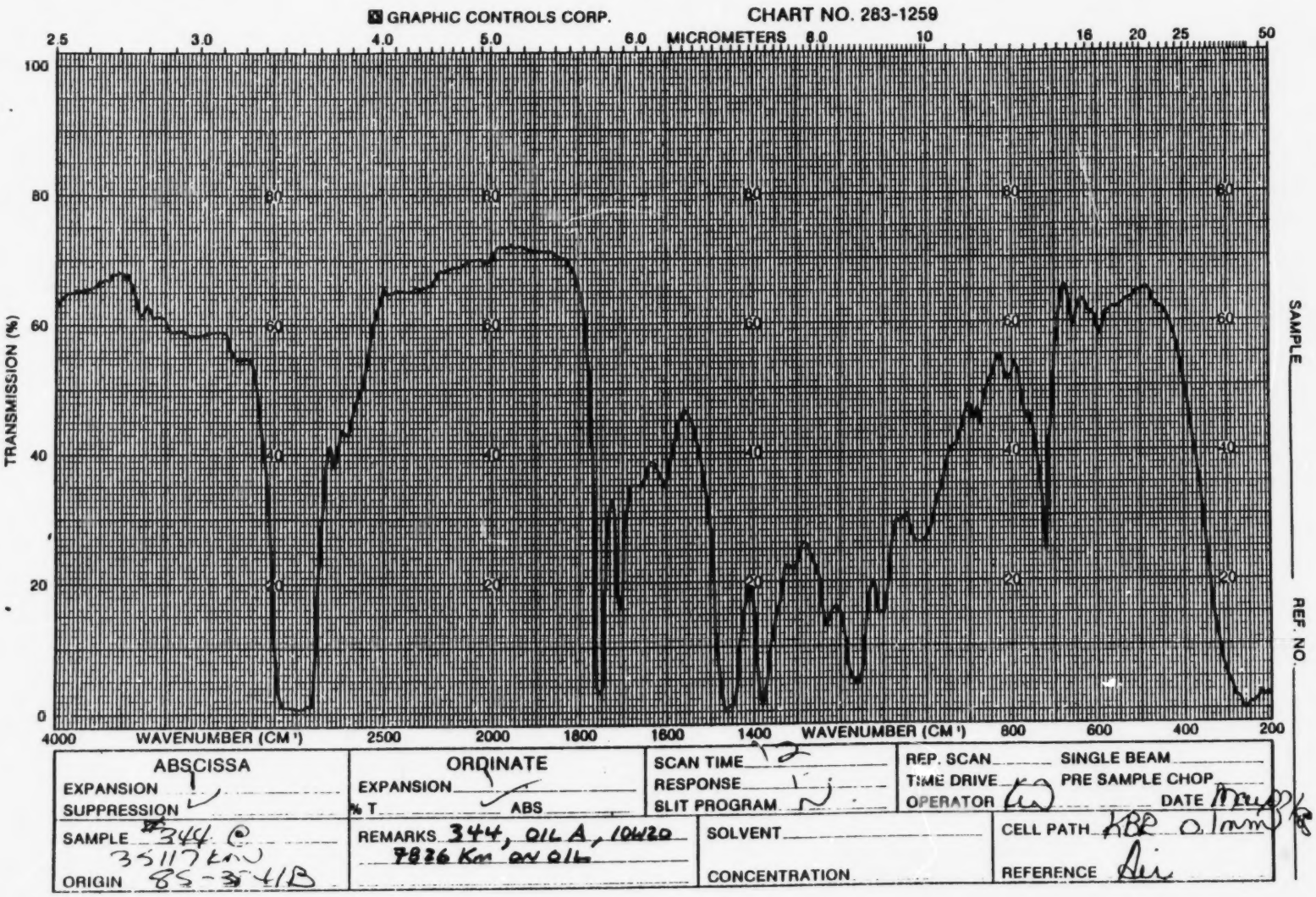

GRAPHIC CONTROLS CORP.
CHART NO. 283-1259
2.5
3.0
4.0
5.0
6.0
MICROMETERS
8.0
10
16
20
25
50
100
80
60
40
20
0
TRANSMISSION (%)
4000
WAVENUMBER (CM⁻¹)
2500
2000
1800
1600
1400
WAVENUMBER (CM⁻¹)
800
600
400
200
SAMPLE
REF. NO.
ABSCISSA
EXPANSION 1
SUPPRESSION
ORDINATE
EXPANSION 1
% T
ABS
SCAN TIME 12
RESPONSE 1
SLIT PROGRAM W
REP. SCAN
SINGLE BEAM
TIME DRIVE
PRE SAMPLE CHOP
OPERATOR Ken
DATE Mar 24/82
SAMPLE Can* 333 & CH2Cl2 85-1711B
REMARKS 333, DIL A, 10W30
5066 Km ON DIL
SOLVENT
CELL PATH .1 BP 0.1mm
ORIGIN
CONCENTRATION
REFERENCE Air


GRAPHIC CONTROLS CORP.
CHART NO. 283-1259
2.5 3.0 4.0 5.0 6.0 MICROMETERS 8.0 10 16 20 25 50
100 80 60 40 20 0
TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF. NO.
ABSCISSA
EXPANSION 1
SUPPRESSION
ORDINATE
EXPANSION 1
% T ABS
SCAN TIME 2
RESPONSE 1
SLIT PROGRAM D
REP. SCAN SINGLE BEAM
TIME DRIVE RRE SAMPLE CHOP
OPERATOR KW DATE Apr 17 82
SAMPLE #321-Q 10 Tack
ORIGIN 85-2329B
REMARKS 334, Oil B, 10 Mil
2995 Kw on Oil
SOLVENT
CONCENTRATION
CELL PATH KBr (.1mm)
REFERENCE Air


GRAPHIC CONTROLS CORP.
CHART NO. 283-1259
2.5 3.0 4.0 5.0 6.0 MICROMETERS 8.0 10 16 20 25 50
100 80 60 40 20 0
TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF. NO.
ABSCISSA
EXPANSION 1
SUPPRESSION ✓
ORDINATE
EXPANSION ✓
% T ABS
SCAN TIME 12
RESPONSE N
SLIT PROGRAM
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR DATE
SAMPLE # 335 @ 1032
85-4108B
ORIGIN
REMARKS 335, OIL C, 10WED
5445 KM ON OIL
SOLVENT
CONCENTRATION
CELL PATH KBr 0.1mm
REFERENCE


GRAPHIC CONTROLS CORP.
CHART NO. 283-1259
2.5 3.0 4.0 5.0 6.0 MICROMETERS 8.0 10 16 20 25 50
100 80 60 40 20 0
TRANSMISSION (%)
4000 WAVENUMBER (CM⁻¹) 2500 2000 1800 1600 1400 WAVENUMBER (CM⁻¹) 800 600 400 200
SAMPLE
REF. NO.
ABSCISSA
EXPANSION 1
SUPPRESSION ✓
ORDINATE
EXPANSION ✓
% T ABS
SCAN TIME 12
RESPONSE 1
SLIT PROGRAM N
REP. SCAN SINGLE BEAM
TIME DRIVE PRE SAMPLE CHOP
OPERATOR Kew DATE Jun 12 85
SAMPLE Ca #3 12 03 R22
85-421 2B
ORIGIN
REMARKS 342, OIL B, 10W30
5740 Km ON OIL
SOLVENT
CONCENTRATION
CELL PATH KBr 0.1mm
REFERENCE Air


SAMPLE
REF. NO.
GRAPHIC CONTROLS CORP.
CHART NO. 283-1259
MICROMETERS
WAVENUMBER (CM⁻¹)
TRANSMISSION (%)
ABSCISSA
EXPANSION
SUPPRESSION
ORDINATE
EXPANSION
% T
ABS
SCAN TIME
RESPONSE
SLIT PROGRAM
REP. SCAN
TIME DRIVE
OPERATOR
SINGLE BEAM
PRE SAMPLE CHOP
DATE 07/16/85
CELL PATH KBr 0.1mm
SOLVENT
CONCENTRATION
REFERENCE Air
REMARKS 343, 1045, 1030
9485 Kin ON OIL
SAMPLE 5-049478
343 @ 47039 KM
ORIGIN 01213


GRAPHIC CONTROLS CORP.
CHART NO. 283-1259
2.5
3.0
4.0
5.0
6.0
MICROMETERS
8.0
10
16
20
25
50
100
80
60
40
20
0
TRANSMISSION (%)
4000
WAVENUMBER (CM⁻¹)
2500
2000
1800
1600
1400
WAVENUMBER (CM⁻¹)
800
600
400
200
SAMPLE
REF. NO.
ABSCISSA
EXPANSION
SUPPRESSION
ORDINATE
EXPANSION
%T
ABS
SCAN TIME
RESPONSE
SLIT PROGRAM
REP. SCAN
TIME DRIVE
OPERATOR
SINGLE BEAM
PRE SAMPLE CHOP
DATE
SAMPLE 344 @ 3511.7 KM
ORIGIN 85-354B
REMARKS 344, OIL A, 10/20
7826 Km on Oil
SOLVENT
CONCENTRATION
CELL PATH KBr 0.1mm
REFERENCE Air

APPENDIX E/ A SURVEY OF GASOLINE ENGINE FIELD TESTS

APPENDIX E/ A SURVEY OF GASOLINE ENGINE FIELD TESTS

To qualify an oil for use in 1980 or later gasoline engines, produced in North America, the American Petroleum Institute (API) requirements for an "SF" quality oil must be met.

There are four basic standardized tests with specific requirements that must be met by a motor oil prior to the use of the term "SF" quality:

1/ The Sequence IID test evaluates the rusting and corrosion characteristics of motor oils and is designed to relate particularly to short-trip service under winter conditions in the upper mid-west United States (US).

2/ The Sequence IIID test evaluates the high-temperature oil thickening characteristics, sludge, and varnish deposits, as well as engine wear of motor oils. This test method is designed to relate to high-speed highway operation under summer conditions in the south and southwest US.

3/ The Sequence V-D test evaluates the sludge and varnish deposits of motor oils and is designed to relate to a combination of low speed, low temperature, stop-and-go city driving, and moderate highway operation in the northwest US.

4/ The Labeco L-38 test evaluates the stability, corrosive tendency, and viscosity change of motor oils at high temperatures.

In general, any field tests of motor oils relate directly to one of these four engine tests. For example, a field test under short-trip, cold engine conditions would relate to the Sequence II-D performance. This indicates that only rusting or corrosion tendencies would be rated, while engine wear would not be evaluated.

These four tests were developed as these areas of performance were found to be most important to ensure acceptable gasoline engine durability. The development of the gasoline engine and its lubricant have been closely intertwined: as engines changed, the lubricant and its quality level changed accordingly.

The possible widespread use of fuel-methanol in the future has only recently been seriously considered. Initially, as the engines are similar for gasoline and fuel-methanol, few problems with engine lubrication were envisioned. However, various researchers [1-9] found that engine durability was a problem, especially under cold engine, short- trip conditions.

The Ford/Shell program, as detailed in this report, addressed the concern that engine wear under these conditions could be critical. As such, no

direct comparison with gasoline-fuelled engines can be made. However, some indications of acceptable engine durability can be inferred from gasoline field tests under various conditions.

Various researchers' data are summarized and the expected engine durability parameters estimated at 20 000 km, the distance accumulation in Phase 4, allowing comparison between the results given in this report and the other results for gasoline.

E.1/ Reference : Pless, L.G., "A Study of Lengthened Engine Oil-Change Intervals," SAE Paper 740139.

No. of Vehicles : 109

Oil Type : 9 oils, SC, SD, SE quality

Oil Viscosity Grade : 20, 30, 40

Oil Drain Period : 16 100 to 41 800 km

Distance Travelled : 37 000 to 257 500 km

Parameters Measured : Cam and lifter, ring gap

Results :

To Final Distance Accumulation (per 257 500 km)	20 000 km Equivalent
Cam and lifter wear:	
17 cars; 95 to 155 μm (S. Florida taxis, 1971)	7.4 to 12.0 μm
18 cars; 65 to 195 μm (S. Florida taxis, 1972)	5.0 to 15.1 μm
11 cars; 70 to 90 μm (C. Indiana taxis 1971)	5.4 to 7.0 μm
Ring gap growth:	
17 cars; Top: 350 to 650 μm	27.2 to 50.5 μm
2nd: 325 to 575 μm (S. Florida taxis)	25.2 to 44.7 μm
18 cars; Top: 250 to 525 μm	19.4 to 40.8 μm
2nd: 325 to 450 μm (S. Florida taxis)	25.2 to 35.0 μm
11 cars; Top: 175 to 200 μm	13.6 to 15.5 μm
2nd: 325 to 400 μm (C. Indiana taxis)	25.2 to 31.1 μm

E.2/ Reference : Rodgers, J.J., and Kabel, R.H.,"Vehicle Evaluation of Synthetic and Conventional Oils," SAE Paper 750827.

No. of Vehicles : 5

Oil Type : 3 synthetic, 1 conventional

Oil Viscosity Grade : 5W20, 10W40

Oil Drain Period : 12 000 to 32 000 km

Distance Travelled : 64 000 km

Parameters Measured : Cam wear, sludge, varnish, and rust

Results :

To Final Distance Accumulation (@ 64 000 km)		20 000 km Equivalent
Cam wear:	0.002 mm to 0.012 mm avg.	0.63 to 3.75 μm
Sludge :	9.6 to 9.8 avg. (10 = Clean)	9.9+
Varnish :	9.7 to 9.8 avg. (10 = Clean)	9.9+
Rust :	8.5 to 9.1 avg. (10 = Clean)	9.5 to 9.7

Comments: Mild test, minimal wear, no advantage of synthetics over conventional oils apparent

E.3/ Reference : Pless, L.G., and Rodgers, J.J., "Cam and Lifter Wear as Affected by Engine Oil ZDP Concentration and Type," SAE Paper 77087.

No. of Vehicles : 127

Oil Type : SE/CC, SE/CD

Oil Viscosity Grade : 10W40, 30, 20W20

Oil Drain Period : 4 800 to 41 800 km

Total Distance Travelled : 37 000 to 259 100 km

Parameters Measured : Cam and lifter wear

Results :

To Final Distance Accumulation (per 10 000 km)	20 000 km Equivalent
Cam and lifter wear	
15 cars; 4.6 to 10.7 μm Indianapolis taxis	9.2 to 21.4 μm
19 cars; 1.3 to 4.6 μm Lansing police cars	2.6 to 9.2 μm
17 cars; 11.9 to 20.1 μm Phoenix and Los Angeles taxis	23.8 to 40.2 μm
5 cars; 10.1 μm San Diego taxis	20.2 μm
2 cars; 3.3 μm California state cars	6.6 μm
6 cars; 2.2 to 4.4 μm GMR general transportation cars	4.4 to 8.8 μm
8 cars; 4.7 to 13.1 μm Ft. Lauderdale taxis	9.4 to 26.2 μm

E.4/ Reference : Bardy, D.C., et al, "A 2.3 L Engine Deposit and Wear Test - An ASTM Task Force Progress Report," SAE Paper 780260.

No. of Vehicles : 61

Oil Type : Various

Oil Viscosity Grade : Various

Oil Drain Period : 9 700 to 32 200 km

Total Distance Travelled : 37 200 to 259 100 km

Parameters Measured : Sludge, varnish, cam wear, cylinder bore wear, bearing weight loss (not done on all cars)

Results :

	To Final Distance Accumulation	20 000 km Equivalent
Sludge :	5.8 to 9.5 (10 = Clean)	9.3+
Varnish :	3.6 to 7.8 (10 = Clean)	8.9 to 9.6
Cam wear :	30.5 to 53.3 μm	<10.2 μm
Lifter wear :	35.6 to 63.5 μm	<10.2 μm
yl. bore wear:	5.1 to 86.4 μm	<15.2 μm
Brng. wt. loss:	73 to 184 mg	<30.9 mg

E.5/ Reference : Miller, M.S., et al, "A Field Correlation of the Sequence V-D Engine Test, SAE Paper 820084

No. of Vehicles : 5

Oil Type : SF, SE/CD

Oil Viscosity Grade : 5W30, 15W40

Oil Drain Period : 12 000 and 24 000 km

Total
Distance Travelled : 72 000 km

Parameters Measured : Sludge, varnish, cam wear, rod bearing wt. loss

Results :

To Final Distance Accumulation		20 000 km Equivalent
Sludge	: 9.6 to 9.7 @ 72 000 km (10 = Clean)	9.9
Varnish	: 8.5 to 9.4 @ 72 000 km (10 = Clean)	9.6 to 9.8
Cam wear	: 5μm to 10μm in for SF oils	
	@ 72 000 km	<2.5μm
	46μm for SE/CD oil @ 53 700 km	<17.8μm
Rod bearing weight loss	: 32.4 to 42.9 mg for SF oils	
	@ 72 000 km	9.0 to 11.9 mg
	64.7 mg for SE/CD oil @ 53 700 km	24.1 mg

E.6/ Reference : Flathmann, D.E., et al, "Wear Performance of an SAE 0W30 Partial-Synthetic Motor Oil Under High Speed Driving Conditions" SAE Paper 821196.

No. of Vehicles : 6

Oil Type : SF Quality

Oil Viscosity Grade : 0W30, 10W30

Oil Drain Period : 12 000 km

Total Distance Travelled : 80 000 km

Parameters Measured : Rod bearings, main bearings, piston rings, cyl. bore, cam wear, sludge, varnish, used oil analysis

Results :

To Final Distance Accumulation (per 80 000 km)		20 000 km Equivalent
Rod bearing weight loss :	42.6 mg	10.7 mg
Main bearing weight Loss:	48.9 mg	12.2 mg
Piston ring weight loss :	Top: 41.9 mg	10.5 mg
	2nd: 25.2 mg	6.3 mg
Cyl. bore wear: 4.3 μm		1.1 μm
Cam Wear: 12 μm		3 μm
Sludge : 9.8 (10 = Clean)		9.9+
Varnish : 8.7 (10 = Clean)		9.7+

Used-oil analysis: (@ 12 000 km drain intervals)	(@ 5000 km drain intervals)
Al 18, 3, 9 (10 avg) ppm	4.2 ppm
Cr 2,1,1 (1 avg) ppm	<1.0 ppm
Cu 3, 33, 3 (13 avg) ppm	5.4 ppm
Fe 37, 15, 50 (34 avg) ppm	5.0 ppm
Si 23, 7, 7 (12 avg) ppm	
Pb 39, 45, 42 (42 avg) ppm	17.5 ppm

E.7/ Reference : Harris, S.W., and Zahalka, T.L., "A Field Test Study of Camshaft Wear in a 2.3 L OHC Engine and Its Correlation to the Sequence V-D Test," SAE Paper 831758.

No. of Vehicles : 20

Oil Type : 5 types SF/CC, SF/CD Quality

Oil Viscosity Grade : 15W40 and 10W30

Oil Drain Period : 24 000 km

Total Distance Travelled : 48 000 to 80 000 km

Parameters Measured : Camshaft wear

Results :

To Final Distance Accumulation	**20 000 km Equivalent**
Cam wear : 12.7 to 20.3 μm @ 16 000 km	15.2 to 2.5 μm
15.2 to 25.4 μm @ 24 000 km	12.7 to 20.3 μm
17.8 to 38.1 μm @ 48 000 km	7.6 to 15.2 μm
Follower wear: <9 mg wt. loss @ 16 000 km	<11.3 mg
<17 mg wt. loss @ 24 000 km	<14.2 mg
Iron level : 163 to 227 ppm @ 24 000 km (1st drain)	34 to 47 ppm (@ 5000 km drains)
145 to 267 ppm @ 48 000 km (2nd drain)	30 to 56 ppm (@ 5000 km drains)

Comments:
- Cam wear is an inverse exponential relation.
- Long drain periods accentuate wear problems.

E.8/ Reference : Smolenski, D.J., and Kabel, R.H., "Effect of Engine Zinc Dithiophosphate (ZDP) Additive Type on Cam and Lifter Wear in Taxi Service," SAE Paper 831760.

No. of Vehicles : 56

Oil Type : 9 types, 3SF, 6 < SF Quality

Oil Viscosity Grade : 10W30 and 20W30

Oil Drain Period : 12 000 km ± 1200 km

Total
Distance Travelled : 108 000 to 165 000 km

Parameters Measured : Sludge, varnish, cam and lifter wear

Results :

To Final Distance Accumulation (per 161 000 km)	**20 000 km Equivalent**
Sludge : 9.3 to 9.6, (10 = Clean)	9.9+
Varnish : 6.0 to 7.3, (10 = Clean)	9.2 to 9.5
Cam and lifter wear:	
Average: 86 to 246 μm	10.7 to 30.6 μm
Maximum: 445 to 1412 μm	55.3 to 175.4 μm
Comments: Long drains in severe service Avg. cam + lifter wear <150 μm Acceptable	18.6 μm

E.9/ Reference : Olson, D.M., and Pullen, G.A., "Engine Wear Protection of SAE 5W30 Oils," SAE Paper 852075.

No. of Vehicles : 4

Oil Type : 2, SF quality

Oil Viscosity Grade : 5W30

Oil Drain Period : 12 000 km

Total Distance Travelled : 82 000 km

Parameters Measured : Sludge, varnish, bearing wear, used-oil analysis

Results :

To Final Distance Accumulation		20 000 km Equivalent
Sludge	9.6 to 9.9 (10 = Clean)	9.9+
Varnish	8.2 to 8.6 (10 = Clean)	9.5 to 9.6
Piston wear	7.9 to 8.9 (10 = Clean)	9.4 to 9.7
Main bearings	11.6 to 192.4 mg average	3.4 to 56.3
Rod bearings	39.8 to 169.4 mg average	11.6 to 49.6
Wear metals (12 000 km intervals)		(@ 5000 km drain intervals)
Fe:	36.4, 34.0, 31.6 32.6, (33.7 avg) ppm	14 ppm
Cu:	5.3, 6.0, 8.6, 6.4 (6.6 avg) ppm	3 ppm
Pb:	25.9, 28.0, 75.0 70.6, (49.9 avg) ppm	21 ppm

E.10/ Comparison of Reported Gasoline Wear Results with Methanol Performance

Parameter	Expected Results with Gasoline @ 20 000 km	Phase 4 Results
Cam and Lifter Wear, μm	15 typ	-
Cam Wear, μm	<20 max 7.5 typ	<27 7.5 typ.
Sludge (10 = Clean)	9.8+	9.7+
Varnish,	8.9 9.5 typ	8.7+
Top ring wt. loss, mg	10.5	84
Top ring gap growth, μm	<46	<44
Cylinder bore wear, μm	<15 max 1.3 typ.	<5 2.5 typ.
Rod bearing wt. loss, mg	<30.9 max <12 typ.	<30.9 <15 typ.
Used oil Fe level, ppm	(@ 12 000 km drains) <56 max <32 typ	(@ 5000 km drains) <80 max <45 typ

APPENDIX F/ CAR 306 TEST DATA

APPENDIX F/ CAR 306 TEST DATA

Test car : 1983 Ford Escort, 4 dr, 1.6 L - HO - 2V - 5M
Canadian Calibration

Test oil : AL 20857 oil code
10W30 SF quality

Test duration: 37 228 km, average drain period of 12 073 km

Cam wear (μm) :

Cylinder 1	ex.	43
	in.	53
Cylinder 2	ex.	51
	in.	46
Cylinder 3	ex.	256
	in.	234
Cylinder 4	ex.	229
	in.	33
Average	ex.	145
	in.	92